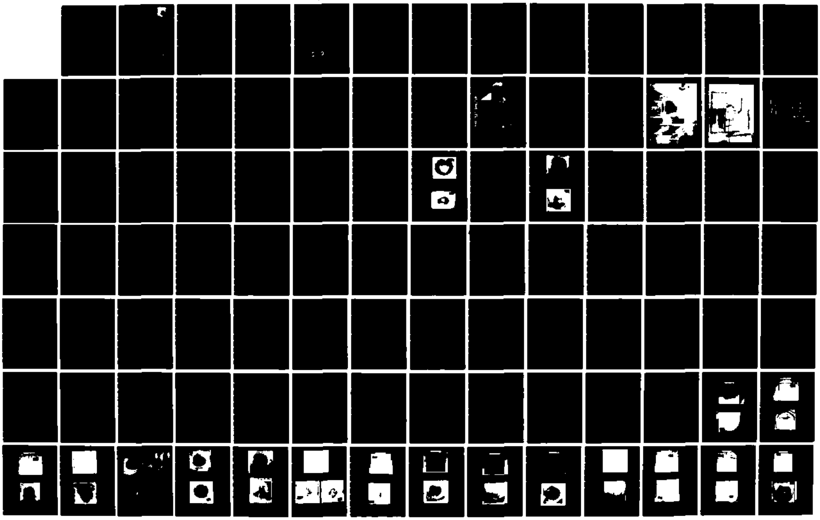
AD-A155 765 INVESTIGATION OF EXPERIMENTAL LIGHTWEIGHT FIREWALL MATERIALS FOR A/C ENGI..(U) AIR FORCE WRIGHT AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH J J MOYER 1/3

UNCLASSIFIED APR 85 AFWAL-TR-84-2082 F/G 11/7 NL



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INVESTIGATION OF EXPERIMENTAL LIGHTWEIGHT FIREWALL MATERIALS FOR A/C ENGINE BAY APPLICATIONS

Jeffrey Moyer, First Lieutenant, USAF
Fire Protection Branch
Fuels and Lubrication Division

April 1985

Final Report for Period 1 October 1983 - 2 May 1984

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This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFWAL-TR-84-2082	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Aero Propulsion Laboratory Aeronautical Systems Division 6b. OFFICE SYMBOL (If applicable) AFWAL/POSH	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Wright-Patterson AFB OH 45433-6563	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Aero Propulsion Laboratory Aeronautical Systems Division 8b. OFFICE SYMBOL (If applicable) AFWAL/POSH	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code) Wright-Patterson AFB OH 45433-6563	10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
PE62203F	3048	304807	30480787

11. TITLE (Include Security Classification) Investigation of Experimental Lightweight Firewall Materials for A/C Engine Bay Applications

12. PERSONAL AUTHOR(S) 1st Lt Jeffrey J. Moyer

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	FROM Oct 83 TO May 84	1985 April	120

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB. GR.
01	03	
11	07	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Fire Test, High Temperature Materials, Firewall, Fire Resistant, Thermal Protection.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

An evaluation of fire-resistant materials was conducted to identify possible replacements for stainless steel for use as aircraft firewalls. The materials were subjected to the standard firewall (MIL-I-83294), fire-penetration test. In addition, each sample passing this test was further evaluated on weight, thermal protection, and maintenance requirements. An attempt was made to correlate physical properties to fire-penetration test performance, but was not successful due to the lack of physical property information. The report identifies those materials which should be developed for use as firewalls and fire-hardening materials on aircraft.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☒ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL 1st Lt Jeffrey J. Moyer, 56918, AFWAL/POSH	22b. TELEPHONE NUMBER (Include Area Code) (513) 255-6918 22c. OFFICE SYMBOL AFWAL/POSH

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

FOREWORD

This report was prepared by 1Lt Jeffrey J. Moyer of the Fire Protection Branch, Fuels and Lubrication Division, Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Aeronautical Systems Division (AFWAL/POSH). The work reported herein was performed under Project 3048, "Fuels, Lubrication, and Fire Protection", Work Unit 30480787, "Aircraft Fire Protection". This report covers research accomplished in-house from October 1983 to May 1984.

The author appreciates the participation of all the companies which supplied samples and information in support of this program. Special thanks are given to Mr John Murphy, AFWAL/POSH, and Mr Augustus Mack, AFWAL/POFF, for their invaluable aid in the execution of the tests.

This report was submitted by the author May 1984.

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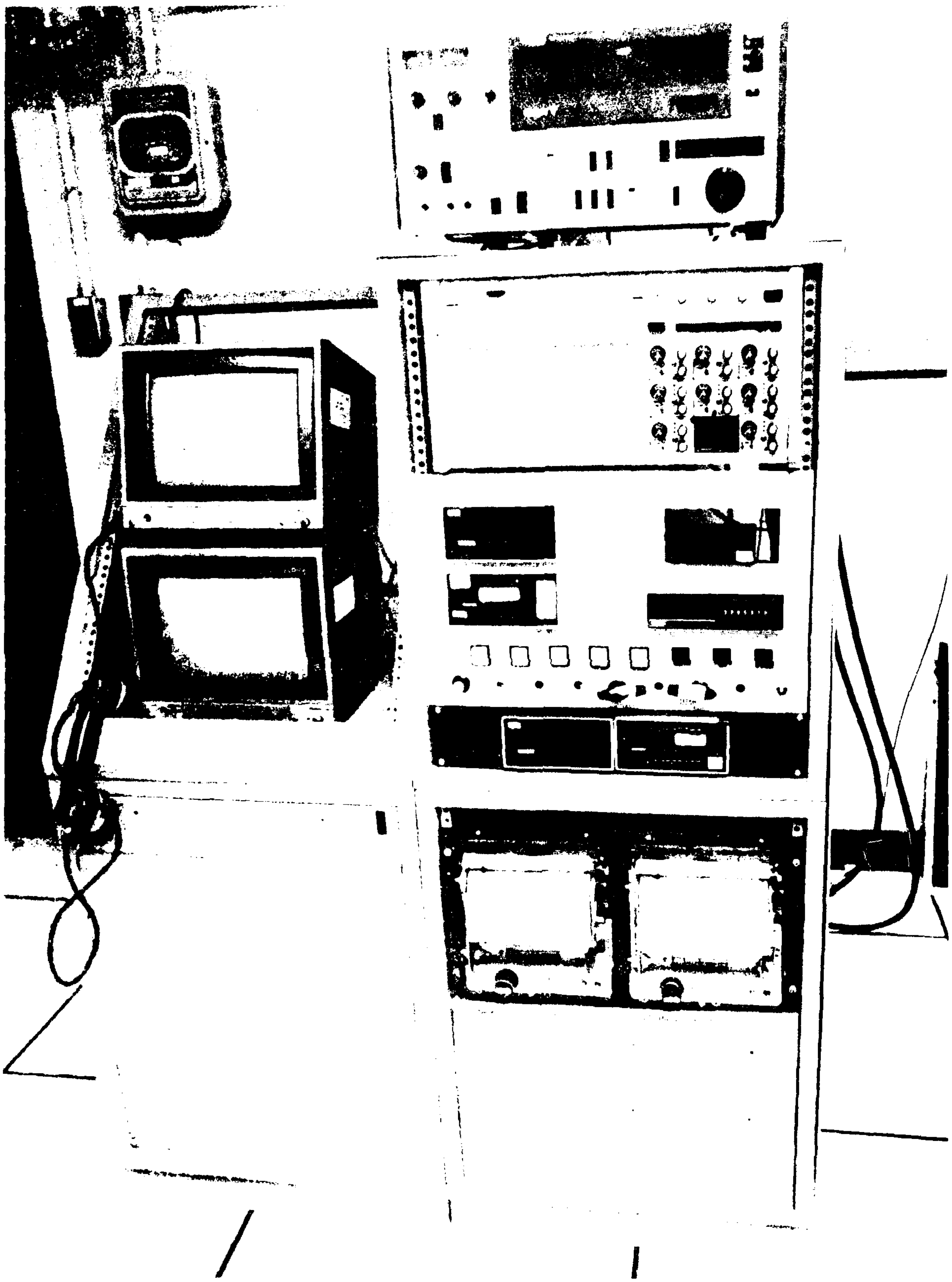

[illegible] and Control Panel

Figure 3. Fire Penetration Test Set-Up Without Sample

camera output could be recorded at any given time. The recording was accomplished on a Sony model VO-5800 Videocassette Recorder. The recorder has variable speed playback, which was used in analyzing the tests.

Figure 2 shows the burner directed at the thermocouple rake used to characterize the flame. Figure 3 shows a test set-up (minus the sample). You can clearly see the thermocouples used to measure flame and surface temperature. Finally, Figure 4 is a picture of the instrumentation panel used to monitor and control the tests.

Testing was conducted in accordance with SAE Aerospace Recommended Practice (ARP) 1055. A 6" x11", 2,000 ± 150°F flame was produced by a Beckett model AF oil burner. The burner was modified according to FAA-RD-76-213, "Re-evaluation of Burner Characteristics for Fire Resistance Tests," to produce a 2,000 ± 150°F flame with a total heat flux between 9.0 and 10.8 $BTU/ft^2/s$. A two-gallon safety can provided enough JP-8 fuel for three tests with the burner operating at a fuel pressure of 90 psig and fuel flow of two gal/hr. The flame was characterized and checked each day by a rake of 11 type K thermocouples and a calorimeter. The thermocouples could be moved to scan the flame temperature in 1" squares as suggested by FAA-RD-76-213. The calorimeter was mounted to have the same capability. Temperatures were recorded using a Honeywell model 1858 Visicorder oscillograph and two chart recorders. The outputs were also parallel wired to a digital display. The calorimeter output was displayed digitally, but was not recorded.

The samples were held on a stainless steel holder by sandwiching them between two identical frames and bolting the three together with ¼" bolts. The rigid structure of the sample holder required the samples to be bolted on two non-opposing sides to limit loading due to thermal expansion. Two small, flat clamps were used to hold thermocouples in place to measure flame and material surface temperature during testing. Flame temperatures were displayed digitally; material temperatures were displayed digitally and recorded on chart recorders, using type K thermocouples.

All tests were recorded on 3/4" video cassettes. Two cameras were used to monitor both flame and non-flame sides of the samples. However, only one

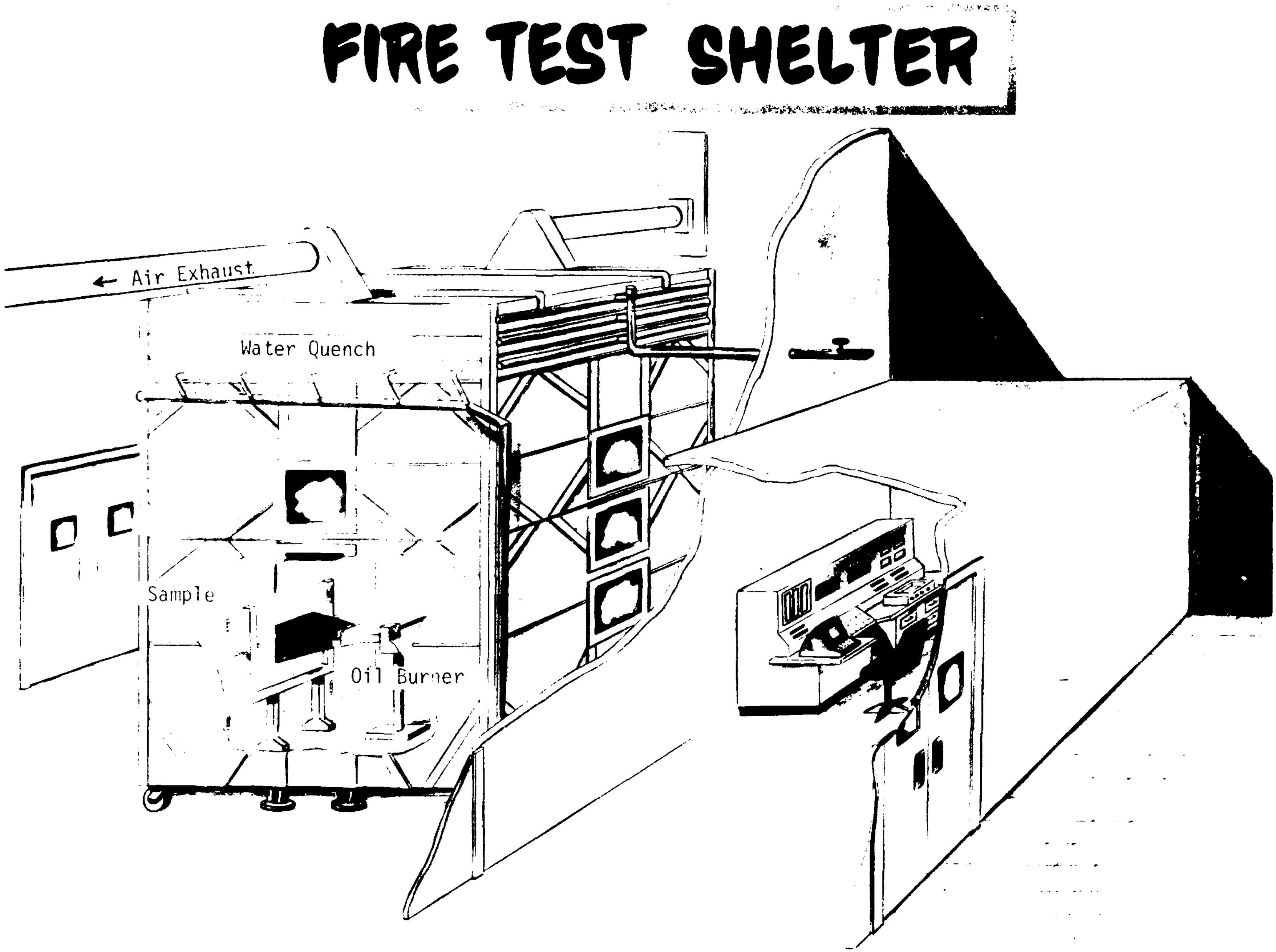

Figure 1. Fire Test Shelter (FTS) Conceptual Drawing

SECTION II

TEST FACILITY

Test Facility

All fire penetration tests were accomplished in the Fire Test Shelter (FTS). The FTS, shown in Figure 1, is a 10' x 10' x 15' high stainless steel structure consisting of two parts. The first part is the test chamber which measures 10' x 10' x 12' high. The chamber is equipped with two large double folding doors which provide easy access. Two 2' x 2' windows allow for safe viewing of the tests and can be placed in any of nine positions. Fire protection is provided by a water fog and water spurt system. The water fog is provided by a single 50 gal/min nozzle located in the center of the test chamber ceiling. The water spurt is used for direct application and consists of a single 18 gal/min nozzle attached to a flexible hose. Both systems are remotely activated by pneumatic valves. A single water line supplies both extinguishing systems, and also an exhaust cooling and cleaning system located in the second part of the FTS, known as the water quench system. The quench system sits on top of the test chamber, and is a network of air channels with 135 spray nozzles that distribute 25 gal/min of water. Air is drawn through the quench and test chamber by two fans located on the roof of the test cell. The FTS sits on screw jacks to allow make-up air to enter the test chamber. Ventilation for this program was maintained at 576 CFM (5.76 ft/min - average velocity in test chamber) to remove combustion products while maintaining quiescent conditions. Air flow is monitored by a sail switch with audible alarm, while air temperature is monitored by two type T thermocouples (one in each vent) and a thermal sensor with audible alarm.

technical papers, and people working in the area of high temperature materials were researched. The final product was a list of 41 companies with products or interest in this area. A letter was sent to each supplier describing the project and asking for an expression of interest. Eventually, 14 companies submitted a total of 68 panels for evaluation by the government. A compete listing of the suppliers and their samples can be found in Appendix A.

to regular maintenance. During maintenance, the firewall is expected to withstand abrasion and banging without degradation. If the firewall does become damaged, it must be easily and quickly repaired. The next logical step was to evaluate the candidate materials on their resistance to accidental damage and their ease of repair.

Stainless steel has very few maintenance problems. Repeated scratches or strikes to the surface with an object show no degrading of its firewall performance. Should a puncture occur, a patch can be quickly riveted in place. This part of the evaluation was the most subjective. Materials were evaluated on their resistance to puncture, abrasion, and capability for repair. This final evaluation was used mainly for ranking materials.

The evaluation criteria were designed to determine the possibility of replacing stainless steel firewalls with a lighter material by comparing the characteristics of stainless steel to the lighter materials. Each material that passed the fire penetration test was evaluated on its aircraft compatibility regardless of its weight or thermal protection. This was done to aid the aircraft designer in choosing fireproof materials for special applications as well as for standard firewalls.

D. Sample Gathering

The samples and suppliers involved in this project were identified from many different sources. Over a period of six months, periodicals, books,

* This temperature is the lowest temperature at which JP-4 has been found to ignite on a hot surface (Reference 8) for most realistic aircraft conditions.

These five areas of evaluation were the fire penetration test, weight, thermal protection, environmental limitation, and maintenance requirements.

The testing conducted in this program was the fire penetration test. This test consists of impinging a 2,000°F flame on a 2' by 2' square sample for 15 minutes. The stainless steel sheet will not allow the flame to penetrate. The test is an FAA standard and a Society of Automotive Engineers Aerospace Recommended Practice (SAE ARP 1055).

A major thrust of this program was the reduction of weight of firewalls. A 2' x 2' piece of 0.015" thick stainless weighs 2.5 pounds. The weight of all samples was recorded and compared to this standard. Those samples weighing 2.5 pounds or less were further evaluated on their thermal protection performance.

A sheet of stainless provides practically no thermal protection, as the non-flame side in a fire penetration test obtains a temperature near that of the flame side. In present aircraft, anything within 4" of a firewall on the non-fire side must be fire resistant (Reference 8). The desired non-flame side temperature is 700°F* or less. Temperatures in this range may reduce the design requirements for components/materials in the area of the non-fire zone side of firewalls. Those materials providing improved or similar thermal protection to stainless were next evaluated on environmental limitations.

Aircraft operate in a wide variety of environmental conditions, from the low temperature and low humidity of high altitude to the high temperature and high humidity of ground tropical operations. The firewalls were evaluated to determine ability to survive under these conditions. In addition to operating in a wide variety of harsh environmental conditions, aircraft are also subject

System Components" (Reference 4). This test standard specifies a modified oil burner as the flame source. This is the same burner discussed in FAA-RD-76-213, "Re-evaluation of Burner Characteristics for Fire Resistant Tests" (Reference 5). This report specifies 2000 ± 150°F flame temperature and total heat flux of 9.0 to 10.8 BTU/ft^2/s. This report was written to update the FAA report, "Power Plan Engineering Report No. 3A," which specifies test procedures (Reference 6). FAA-RD-76-213 compares the oil burner to a cluster of propane torches. A propane torch is described in SAE Aerospace Standard 401B, "Power Plant Fire Detection Instruments - Thermal and Flame Contact Types (Reciprocating Engine Powered Aircraft)" (Reference 7). This propane torch has been used by many people in place of the oil burner. Both produce the 2,000 ± 150°F flame temperature, and not until the FAA re-evaluation was it shown that the propane torch produced only 85% of the total heat flux produced by the oil burner. This finding led to the requirement of having heat flux measurements along with temperature when calibrating the oil burner.

Along with the controversy surrounding the flame source, concern has been shown over lack of screening criteria for fireproof materials. Many materials were projected to last 15 minutes, but burned through within the first five minutes of the test. Analysis has been conducted on ablative materials to determine time to failure, but no application has been made towards other materials. This lack of information led to the second objective of this program, correlating physical properties to fire test performance.

C. Evaluation Criteria

The sample materials were evaluated in five different areas. In each area, the samples were compared to 0.015" thick stainless steel performance.

around standard insulating material have been used for thermal protection, but again, this configuration has limited use because of the weight penalty. Efforts to increase aircraft performance have impacted the use for firewalls due to the weight penalty.

The desire for lightweight materials and the availability of many new high temperature, insulating materials from the space and energy conservation programs led to the initiation of this program.

In 1976, a specific problem was identified on the F-14 that required fire hardening of components, such as tubes and wiring (Reference 1). A thorough test program was conducted to evaluate materials for use on this aircraft in a specific area. This type of testing has since been repeated, but no generic, fireproof material evaluation test program has been conducted.

AFWAL/POSH has seen the need for generic-type testing along with the immense possibilities of these new materials, and in response to TN-ASD-AFWAL/PO-1107-82-18, initiated this program to identify and evaluate materials for use as firewalls and for fire hardening.

The technology need, TN-ASD-AFWAL/PO-1107-82-18, originating in ASD/ENFEF, entitled "Aircraft Fire Containment and Hardening," expresses the desire for evaluation of new materials for fire barriers with equal or better performance than present materials (Reference 2). Firewall performance is specified in MIL-I-83294. It states, "All firewalls shall be constructed of 0.015" thick (minimum) stainless or other material which will withstand 2,000°F for 15 minutes" (Reference 3). For test equipment and procedures, MIL-I-83294 refers to Society of Automotive Engineers Aerospace Recommended Practice (SAE-ARP) 1055, "Fire Resistance and Fire Test Requirements for Fluid

SECTION I

INTRODUCTION

A. Introduction

The use of firewalls for fire containment is an old and proven concept dating back to 1947. The standard firewall was, and still is, a sheet of 0.015" thick CRES stainless steel. This standard firewall provides excellent fire penetration protection, but may result in high backside temperatures and a costly weight penalty. Possible weight reduction and increased thermal protection (low backside temperatures) were the motivating factors for this program.

The objective of this program is twofold:

1. Identifying and evaluating materials to replace stainless steel as firewalls which are lighter and less thermally conductive.
2. Correlating physical properties to fire penetration test performance to aid in developing new materials for use as fire barriers.

To achieve these objectives, the candidate materials were subjected to the Air Force standard firewall test (MIL-I-83294), and the physical properties of the materials and environment compatibility were collated.

B. Background

In the past, firewalls were constructed of 0.015" thick CRES stainless steel or titanium. These materials, although effective, have limited configurations. They also have a relatively high weight penalty and provide no thermal protection. In some instances, blankets of stainless steel foil

SUMMARY

The concept of fire protection by containment is an old and proven one. However, the weight penalty and configuration limitations of present techniques (stainless steel, etc.) have led to the search for new materials. This report presents the results of a study of 68 candidate materials. The candidates were subjected to the standard firewall, fire penetration test. The passing materials were further evaluated on weight penalty, thermal protection, environmental limitations, and maintenance requirements. Many of the materials tested were experimental in nature and much of the information requested was unavailable. All information gathered is presented in this report.

In addition to evaluating new materials, an attempt to correlate physical property data to fire penetration performance was made. Again, due to lack of data, a correlation could not be reached. This points to the need for analytical studies on the fire test system to provide insight for screening and developing new materials.

A total of 39 samples passed the test and are described in this report. Of the 39 samples, 11 were shown to be superior and should be considered for use as firewalls.

SECTION III

FIRE PENETRATION TESTS

A. Test Description

The fire penetration tests were conducted in accordance with SAE ARP 1055. Each 2' X 2' sample panel was bolted to a stainless steel frame and placed 4" from the burner tube. The sample was held vertically with the flame directed at its center. Two thermocouples were attached to the steel frame to measure flame temperature ¼" in front of the sample. Two more thermocouples were attached to the back of the steel frame to measure the sample surface temperature on the non-flame side. After the sample, thermocouples, and burner were in place, all personnel left the FTS, closed the doors and entered the control room. The ventilation was set at 576 CFM, and the water quench system was activated.

The test was started by turning on the video recorder, chart recorders, followed immediately by the burner. A timer on the video recorder was used to time the test. Material surface temperatures were recorded on the chart recorders, and simultaneously were hand recorded at 1, 3, 5, 7, 10, 12, and 15 minutes. Any physical changes to the samples were also recorded on a standard form shown below. Tests were terminated when failure occurred or after 15 minutes, by turning off the burner and chart recorders, then waiting at least 10 seconds before turning off the video recorder.

DATE:
SAMPLE ID:

PASS FAIL ABORT TEST LENGTH:_____

1 MIN:
3 MIN:
5 MIN:
7 MIN:
10 MIN:
12 MIN:
15 MIN:

MAX. BACKSIDE TEMP:_____°F

Figure 5. Fire Penetration Test Data Sheet

B. Test Results and Discussion

Table 1 lists the 39 samples of the original 68 which passed the fire penetration test. This represents a better than 50% success rate. Also included on the table are the physical properties of these samples. The attempt to correlate physical properties to test performance was hampered by the lack of data. Many of the materials tested were experimental or composites for which the type of data is not yet available. Another problem encountered was measuring the properties desired at the elevated temperatures involved in the test. Data from tests at the standard 70°F were used in some cases, but are not reliable for our temperature range. Table 2 provides ranges of the physical properties for those materials passing and failing the test. A complete list of materials and their properties can be found in Appendix A. Both groups had materials with similar properties. The only significant factor is the failure rate on those materials with melt or decomposition temperatures below 2000°F. Although not conclusive, this criteria is a good screening device. The inconclusiveness of the correlation attempt points out the need for analytical studies on the fire test system. In addition, Table 3 lists the samples which failed and their times to failure. This information should be helpful for those people requiring less protection.

TABLE 2

Physical Property Comparison of Materials Passing and Failing the Fire Prevention Test

Physical Property	Passing Material	Failing Material
Density, (lb/ft^3)	0.9125-112	11.5-100
Specific Heat, C_p (BTU/lb-°F)	0.265-0.387	0.33-0.387
Thermal Conductivity, k(BTU-in/hr-ft^2-°F)	0.42-2.62	0.055-1.5
Melt of Decomposition Temperature, T_m(°F)	250-5000	400-5000

Varying degrees of damage were encountered by the samples during testing. Failures ranged from the catastrophic shown in Figure 6 to small cracks as shown in Figure 7. Some failures were caused by the appearance of flame on the backside without burnthrough.

TABLE 1

SAMPLES THAT PASSED THE FIRE PENETRATION TEST

SAMPLE

1. DH-242 BRUNSMET^R Web Insulating Panel
2. INTERAM^R Brand Fire Barrier CS-195
3. INTERAM^R Brand Fire Barrier M20 A
4. NEXTEL^R 5H-13 Fabric
5. NEXTEL^R 5H-13 (w/Aluminum Back)
6. NEXTEL^R 5H-13 Fabric (w/CR_2O_3 Coating)
7. NEXTEL^R B-10 Fabric (w/Aluminized Film)
8. NEXTEL^R 5H-26 Fabric (w/Neoprene Coating)
9. NEXTEL^R 312 Blanket
10. NEXTEL^R 5H-40 Fabric
11. NEXTEL^R 5H-13 (w/Silver Coating)
12. Vought B
13. Quilite^R-XS
14. Quilite^R-XS 758A
15. Flexible Min-K^R HTS
16. Flexible Min-K^R HTS 758A
17. Metal Clad SK4242Q
18. Metal Clad SK4242C
19. Eccolite LN1478-39 #2
20. C-G #4530-1
21. C-G #4530-4
22. Fibrelam^R 3000

TABLE 1 (Continued)

SAMPLES THAT PASSED THE
FIRE PENETRATION TEST

SAMPLE

23. F-263 Epoxy Resin Composite Firewall 114B-79

24. F-263 Epoxy Resin Composite Firewall 114B-80 with Honeycomb Core

25. F-120 Phenolic Resin Composite Firewall 114B-82 with Honeycomb Core

26. F-825 Phenolic Resin Composite Firewall 114B-85 with Honeycomb Core

27. F-174 Polyimide Resin Composite Firewall 114B-86

28. F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core

29. F-178 BMI Resin Composite Firewall 114B-88

30. F-178 BMI Resin Composite Firewall 114B-89 with Honeycomb Core

31. Boeing Symmetrical NEXTEL® - Graphite Panel

32. Solimide® BD6F-13

33. Solimide® BD6M-11

34. Solimide® GL8S-180

35. Solimide® BD5M-12

36. F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket

37. F-174 Polyimide Resin Composite Firewall 114B-97 with Filled Honeycomb Core

38. F-174 Polyimide Resin Composite Firewall 114B-98 with Honeycomb Core and Ceramic Blanket

39. K-Karb™
K-Karb™ w/Silicon Carbide Infusion

TABLE 3

FAILING SAMPLES AND TIMES TO FAILURE

	SAMPLE	TIME TO FAILURE (MIN:SEC)
1.	NOR*FAB 800 Fabric 28 HT 110 Plain	2:30
2.	NEXTEL 5H13 Fabric w/Silicon Rubber Coating	1:00
3.	Foamega	1:18
4.	Vought A	3:00
5.	Vought C	4:30
6.	Dow Corning ^{R}E6052-77-1	0:30
7.	Dow Corning ^{R}E6052-77-2	0:42
8.	Dow Corning ^{R}E6052-77-3	1:00
9.	Dow Corning ^{R}E6173-31-1	0:52
10.	Dow Corning ^{R}E6173-31-2	0:50
11.	Dow Corning ^{R}HX35800	1:30
12.	Dow Corning ^{R}X35066	1:20
13.	Eccolite LN 1478-39 #1	2:10
14.	Eccolite LN 1478-40	1:40
15.	691-1	2:30
16.	691-2	1:40
17.	691-4	1:40
18.	691-5	0:30
19.	691-6	2:50
20.	691-7	2:50
21.	691-8	0:45

TABLE 3 (Continued)

FAILING SAMPLES AND TIMES TO FAILURE

SAMPLE	TIME TO FAILURE (MIN:SEC)
22. Fibrelam Type 1	4:30
23. Fibrelam Type 1 w/Flamarrest	4:30
24. Fibrelam 4000 Type 1	6:30
25. F-120 Phenolic Resin Composite Firewall 114B-81	0:20
26. F-825 Phenolic Resin Composite Firewall 114B-84	0:15
27. Solimide[R] BCM-25	15:00
28. Peek Graphite Composite Panel	11:15

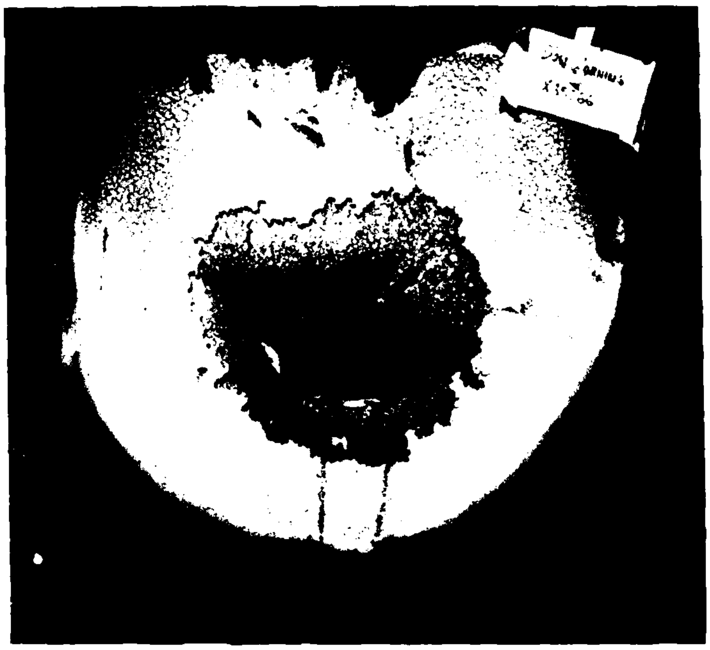

Figure 6. Catastrophic Failure of Sample from Fire Penetration Test

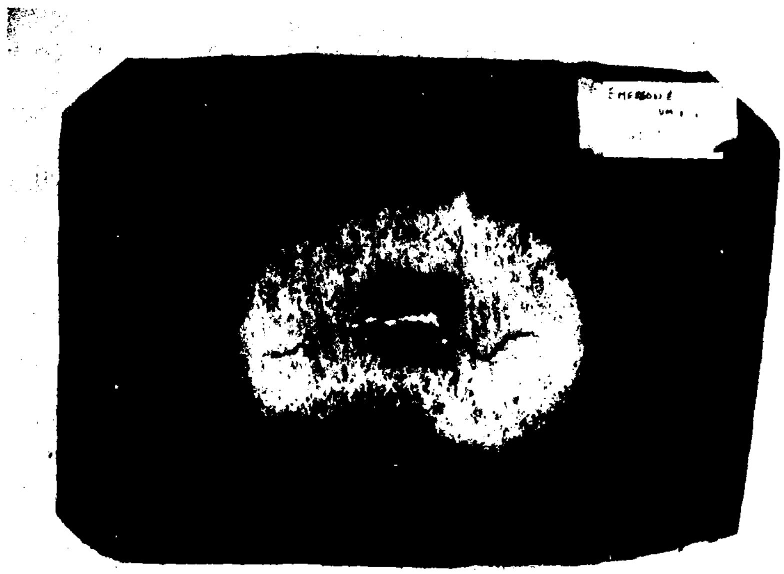

Figure 7. Crack Failure of Sample from Fire Penetration Test

In these cases, resins or solvents were ignited by the high temperatures. Even the successful panels had varying degrees of damage. These varied from soot accumulation as seen in Figure 8 to actual material loss after cool down as seen in Figure 9. A complete set of before and after test pictures for successful panels can be found in Appendix B.

Several problems were encountered during testing with temperature measurements. In the early stages of testing, the thermocouples used to measure the material surface temperature were routinely being broken and burned. This problem was one reason for using two thermocouples to measure surface temperature. The problem was solved by using longer, thicker thermocouples. However, another problem encountered using the steel sheathed probes was keeping the tip on the material surface during testing. The probes were bent slightly to keep a light constant pressure on the sample. However, during testing, the samples often deformed thus increasing or decreasing this pressure. In one instance, one of the probes lost contact with the material. The chart recording verified this by erratic and lower temperature readings. In other cases, the pressure increased so that the probe was close to puncturing the sample. To alleviate this problem and increase the accuracy of these readings, it is suggested that an infrared thermography system be used to measure material surface temperature. This will simplify test preparation and pick up hot spots that an array of thermocouples might miss.

All tests were recorded on a video cassette recorder and were reviewed later. These recordings helped verify the timing of events and allowed for detailed viewing of the tests using the slow playback feature. The lack of proper lighting and equipment prevented us from taping both sides of the tests simultaneously. This drawback to the test facility is being corrected before further testing takes place.

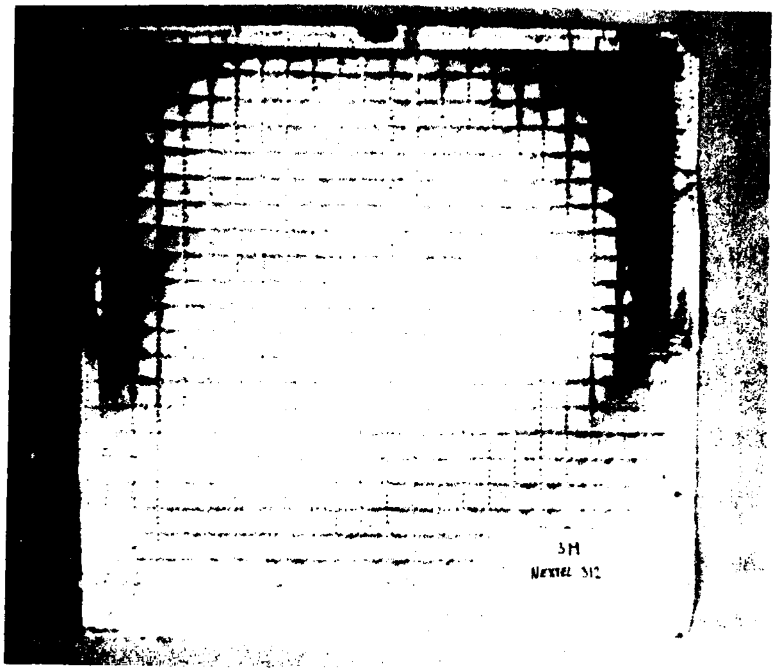

Figure 8. Soot Accumulation on Nextel R 312 Blanket

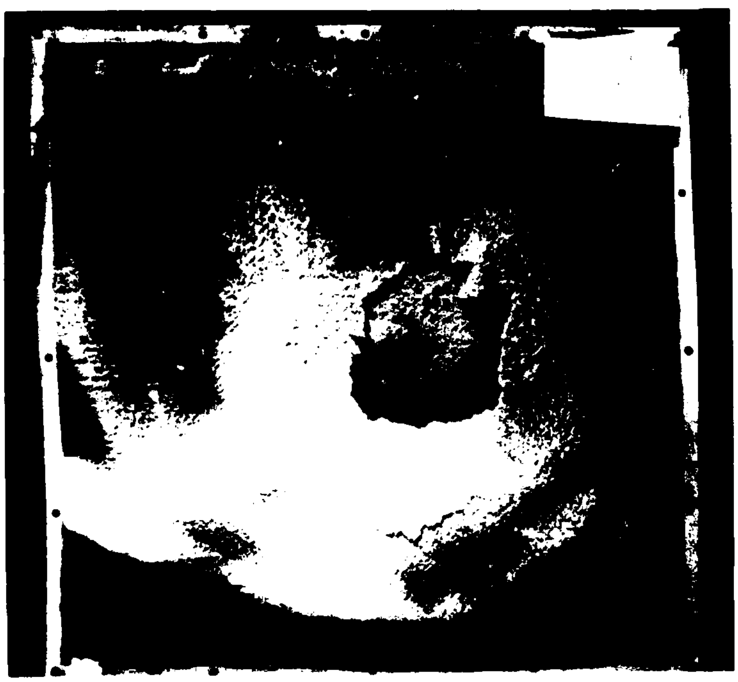

Figure 9. Eccolite LN1478-39 #2 Showing Material Loss After Cooling Down

The test itself proved quite consistent. The burner was calibrated each day with a rake of eleven thermocouples, and only minor adjustments were needed. Often, only proper placement of the thermocouple rake was needed. During testing, however, the flame temperature seemed to vary as much as 300°F from test to test. We later realized these fluctuations were caused by the placement of the thermocouples. The clamps holding them in place became deformed and allowed the thermocouples to wander slightly. This, combined with the air flow caused by the flame, moved the thermocouple down and to the side where the temperatures were lower. All temperatures reported herein are ±5°F as dictated by the accuracy of the chart recorders.

Some of the samples tested in this process had been tested previously with a propane torch. Comparison of these results with ours showed that the oil burner produces a much more severe flame than the propane torch. Therefore, it is desirable to use the oil burner as the flame source when conducting fire penetration testing.

SECTION IV

MATERIAL EVALUATION

After the fire penetration tests were completed, those materials which passed were further evaluated on their aircraft environment compatibility, and compared to the performance of stainless steel in the areas of weight and thermal protection. The information presented in this section was supplied by the sample suppliers through correspondence and conversations.

A. Weight

A major thrust of this program was reducing the weight of firewalls. A standard 2' x 2', 0.015" thick CRES stainless steel panel weighs 2.5 pounds. Table 3 presents the samples which passed the fire penetration test and their weight. As can be seen, 26 of the 39 materials weighed less than 2.5 pounds. The lightest sample which could be used in an aircraft as a non-structural wall weighs only 0.62 pounds. This represents a 75% weight savings over stainless steel. Several others weighed between 1.25 and 2.00 pounds which represents 20-50% weight savings. The 3M samples would weigh approximately one pound more used with the aluminum backing as would be necessary if they were to be used as firewalls. In addition, the Brunswick, Kaiser, and Imi-Tech samples could possibly be made lighter without affecting their fire penetration protection.

B. Thermal Protection

Another area for improvement of existing firewalls is the thermal protection they provide. A stainless steel firewall provides very little thermal protection. This is recognized by the fact that the Air Force requires materials within 4" of a firewall on the non-fire side to be fire resistant. This requirement increases cost and weight and also produces routing problems for plumbing and wiring.

TABLE 4

PASSING SAMPLES AND WEIGHTS

SAMPLE	WEIGHT (LB)
1. DH-242 BRUNSMET^R Web Insulating Panel	6.400
2. Interam^R Brand Fire Barrier CS-195	11.000
3. Interam^R Brand Fire Barrier M20 A	5.040
4. NEXTEL^R 5H-13 Fabric	0.250
5. NEXTEL^R 5H-13 Fabric (W/Aluminum Back)	0.250
6. NEXTEL^R 5H-13 Fabric (W/CR_2O_3 Coating)	0.250
7. NEXTEL^R B-10 Fabric (W/Aluminized Film)	0.250
8. NEXTEL^R 5H-26 Fabric (W/Neoprene Coating)	1.000
9. NEXTEL^R 312 Blanket	1.000
10. NEXTEL^R 5H-40 Fabric	0.700
11. NEXTEL^R 5H-13 (W/Silver Coating)	0.350
12. Vought B	1.170
13. Quilite^R-XS	1.060
14. Quilite^R-XS 758A	3.510
15. Flexible Min-K^R HTS	1.970
16. Flexible Min-K^R HTS 758A	3.670
17. Metal Clad SK4242Q	1.570
18. Metal Clad SK4242C	1.700
19. Eccolite LN1478-39 #2	2.060
20. C-G #4530-1	2.600

N/A NOT AVAILABLE

TABLE 4 (Continued)

PASSING SAMPLES AND WEIGHTS

SAMPLE	WEIGHT (LB)
21. C-G #4538-4	3.900
22. Fibrelam[R] 3000	2.700
23. F-263 Epoxy Resin Composite Firewall 114B-79	2.480
24. F-263 Epoxy Resin Composite Firewall 114B-80 with Honeycomb Core	2.390
25. F-120 Phenolic Resin Composite Firewall 114B-82 with Honeycomb Core	1.460
26. F-825 Phenolic Resin Composite Firewall	1.470
27. F-174 Polyimide Resin Composite Firewall 114B-86	0.620
28. F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core	2.480
29. F-178 BMI Resin Composite Firewall 114B-88	3.450
30. F-178 BMI Resin Composite Firewall 114B-89 with Honeycomb Core	3.120
31. Boeing Symmetrical Nextel[R] - Graphite Panel	1.410
32. Solimide[R] BD6F-13	4.400
33. Solimide[R] BD6M-11	4.600
34. Solimide[R] GL8S-180	2.300
35. Solimide[R] BD5M-12	2.070
36. F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket	2.050
37. F-174 Polyimide Resin Composite Firewall 114B-98 with Filled Honeycomb Core	1.970

N/A NOT AVAILABLE

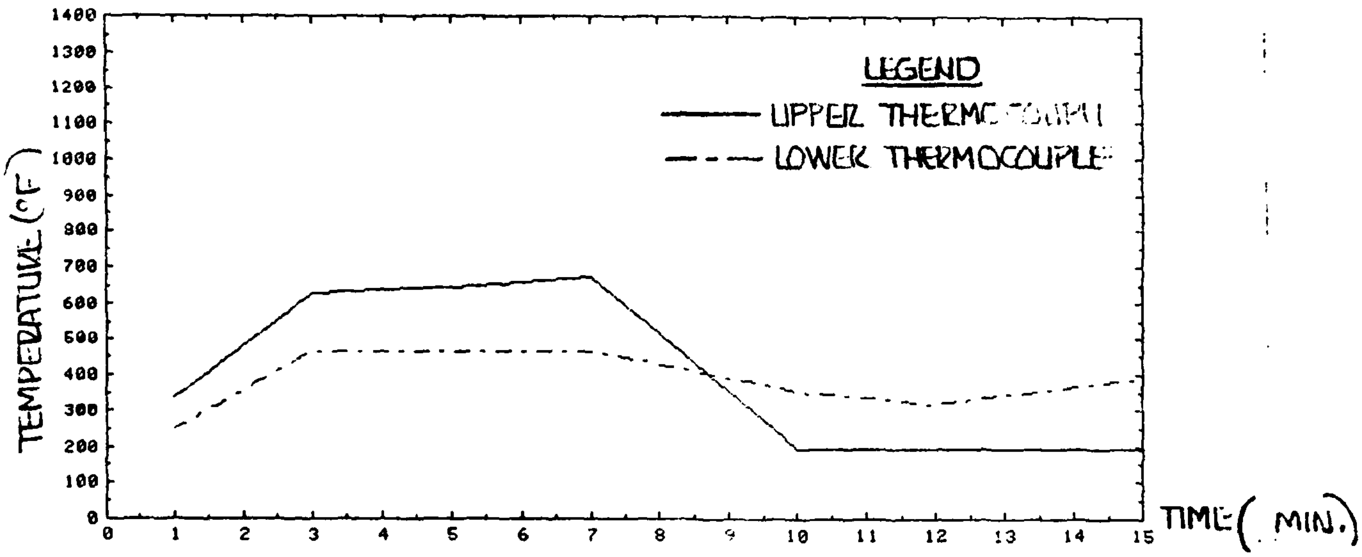

Figure 26. Non-Flame Side Temperature Profile of F-825 Phenolic Resin Composite Firewall 114B-85 with Honeycomb Core

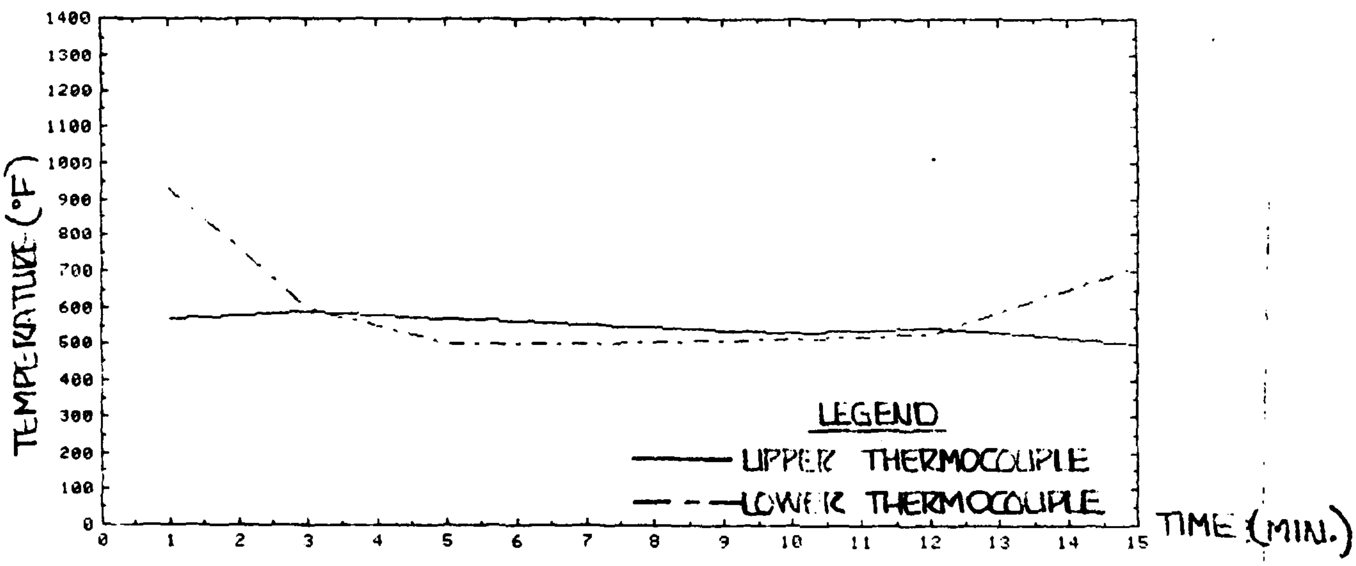

Figure 27. Non-Flame Side Temperature Profile of F-174 Polyimide Resin Composite Firewall 114B-86

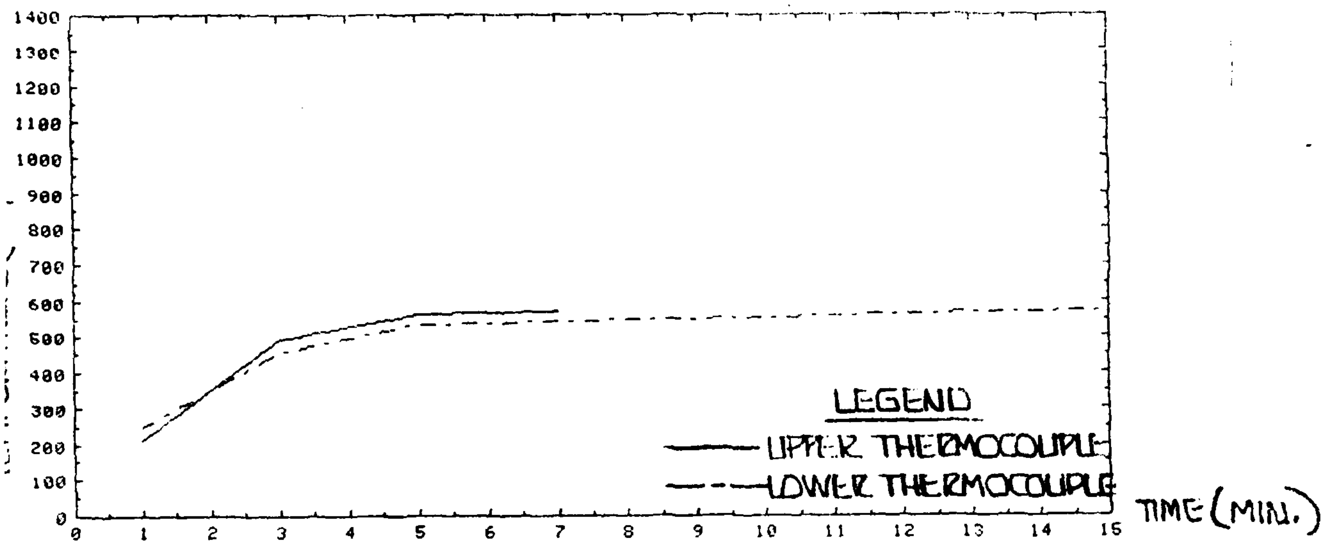

Figure 24. Non-Flame Side Temperature Profile of F-263 Epoxy Resin Composite Firewall 114B-79

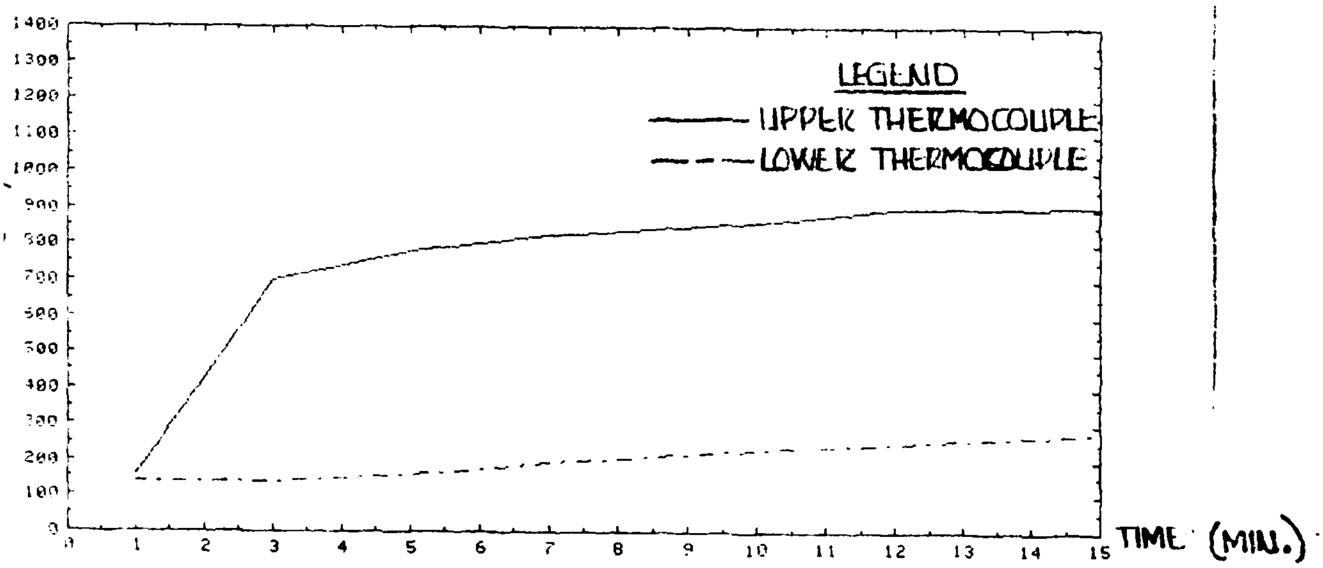

Figure 25. Non-Flame Side Temperature Profile of F-263 Epoxy Resin Composite Firewall 114B-80 with Honeycomb Core

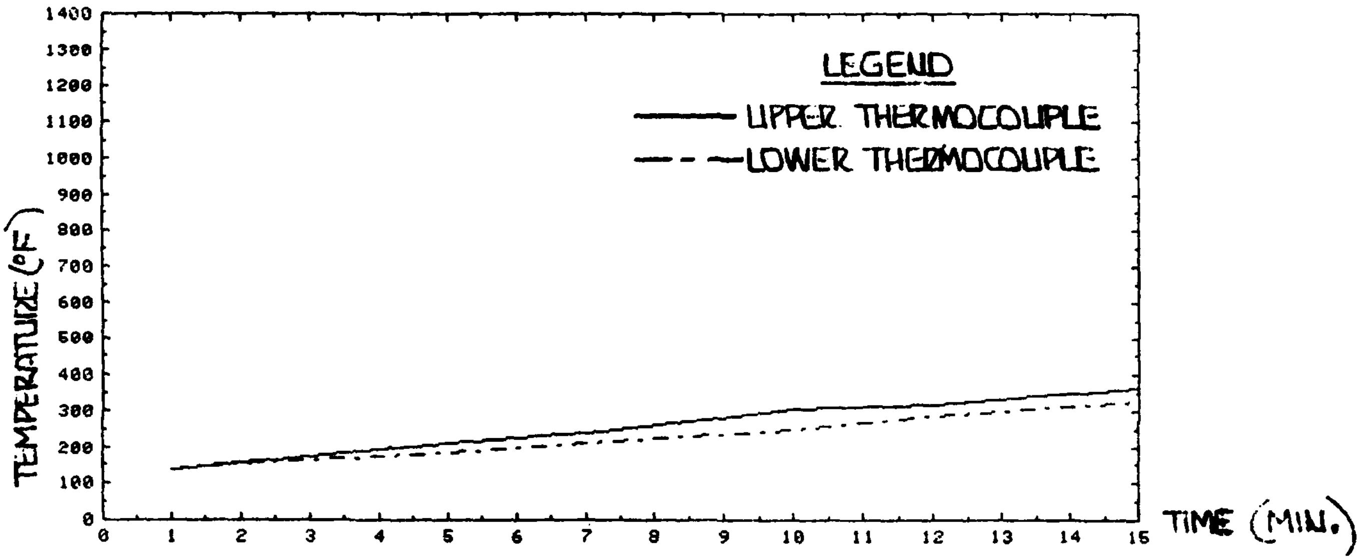

Figure 22. Non-Flame Side Temperature Profile of Eccolite LN1478-39 #2

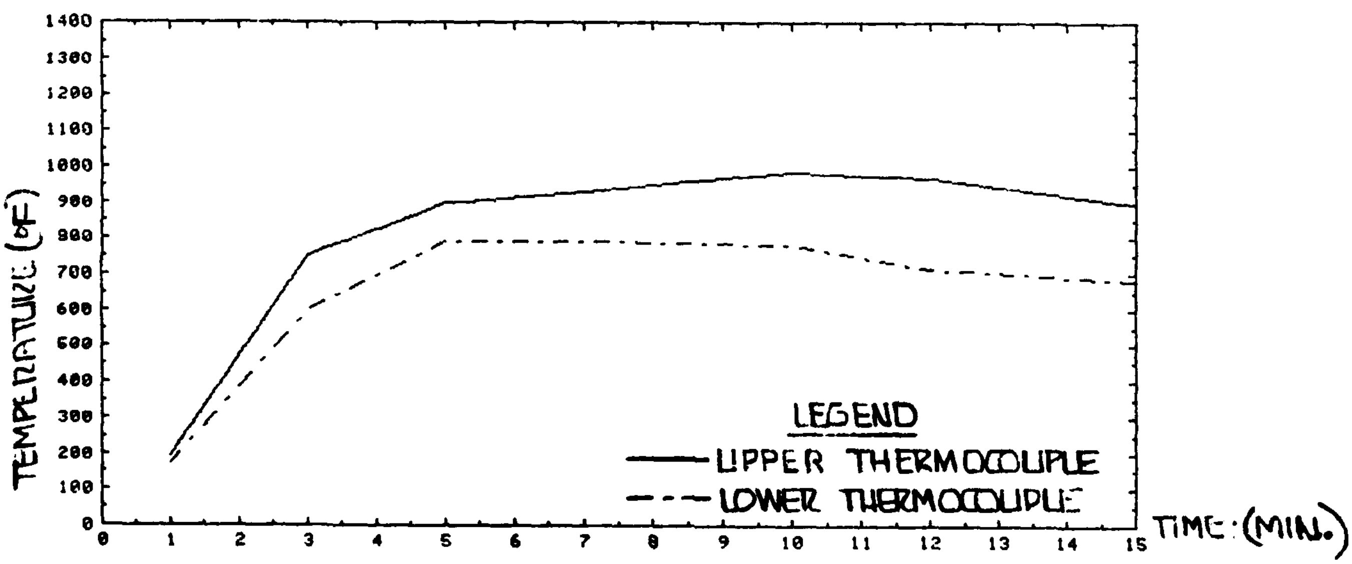

Figure 23. Non-Flame Side Temperature Profile of CG #4530-1

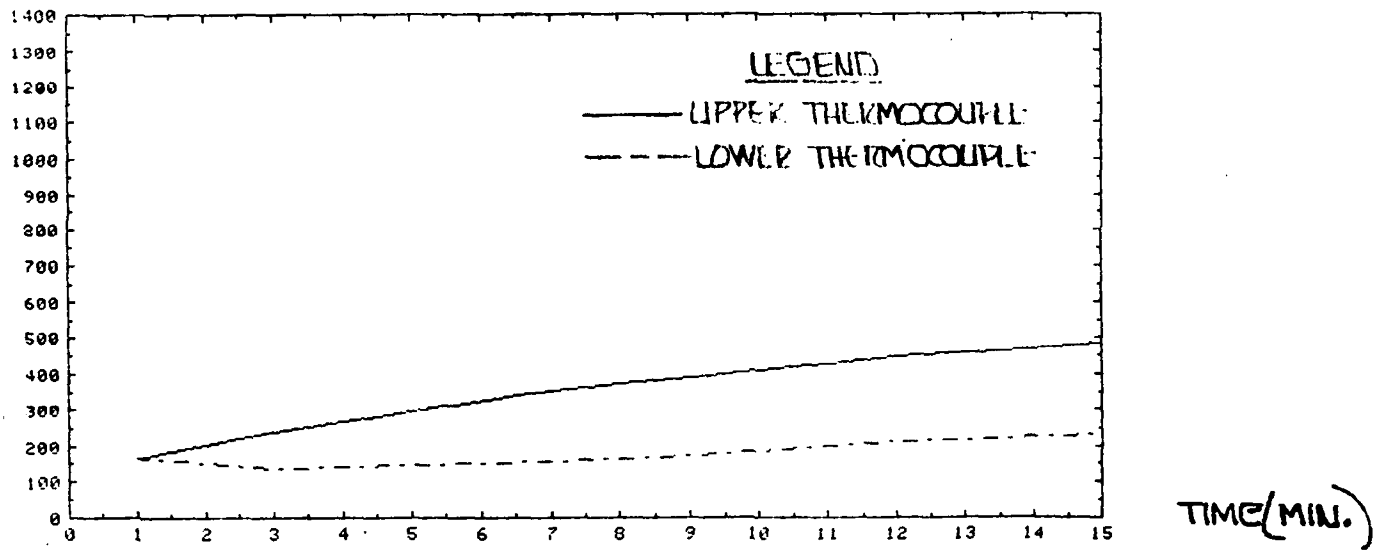

Figure 20. Non-Flame Side Temperature Profile of Metal Clad SK4242Q

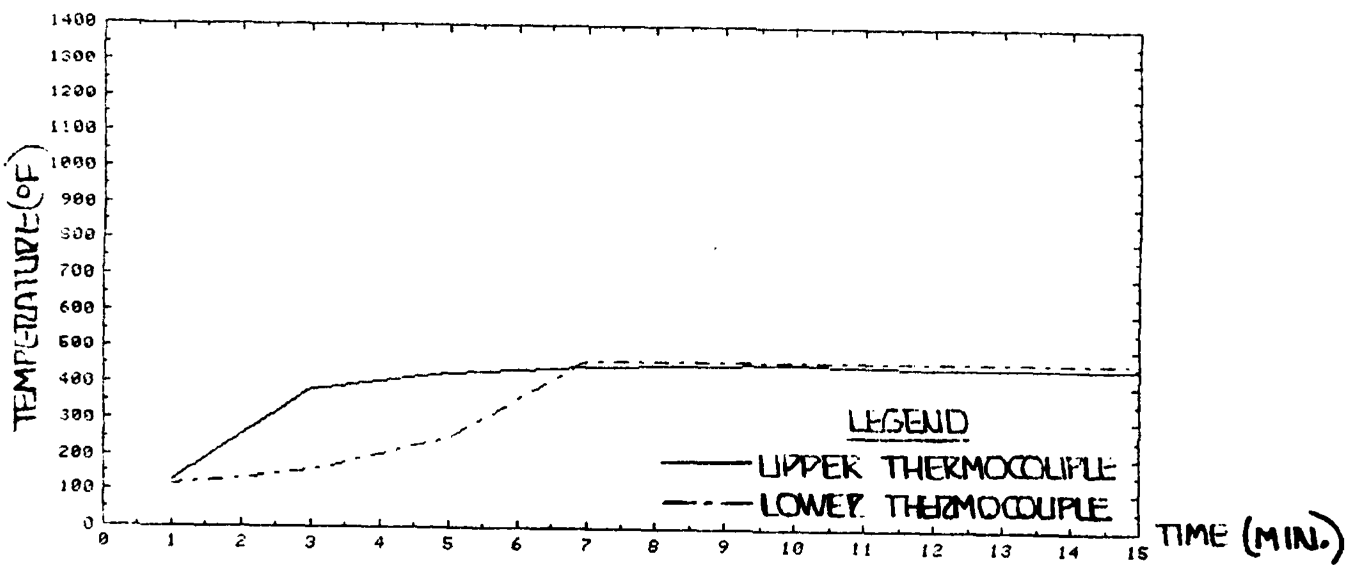

Figure 21. Non-Flame Side Temperature Profile of Metal Clad SK4242C

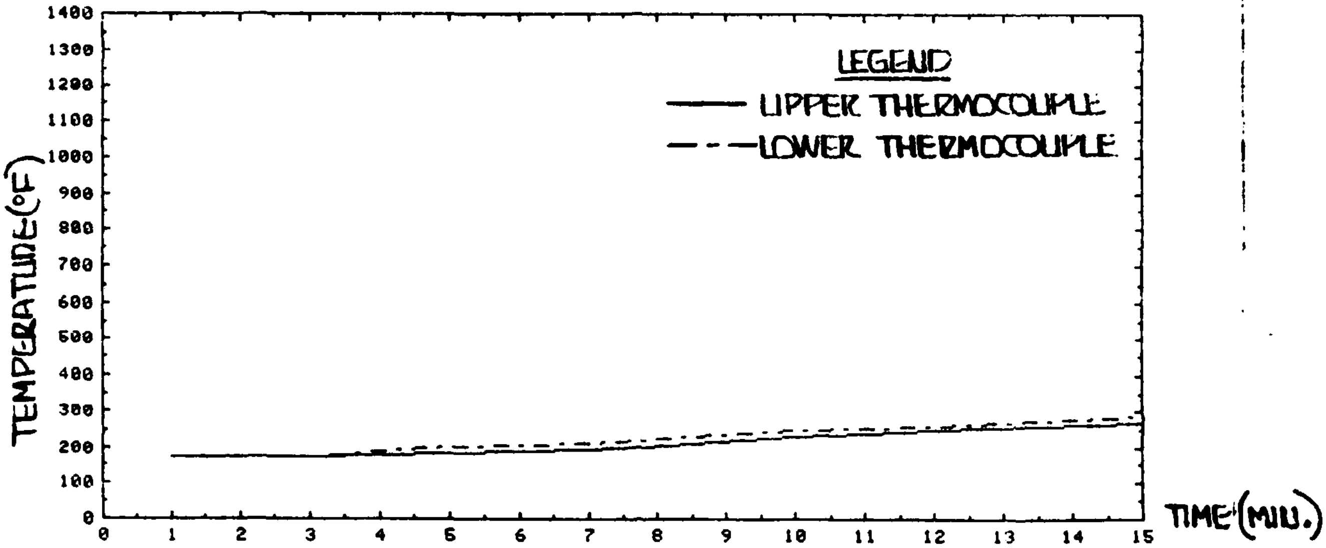

Figure 18. Non-Flame Side Temperature Profile of Quilite[R]-XS

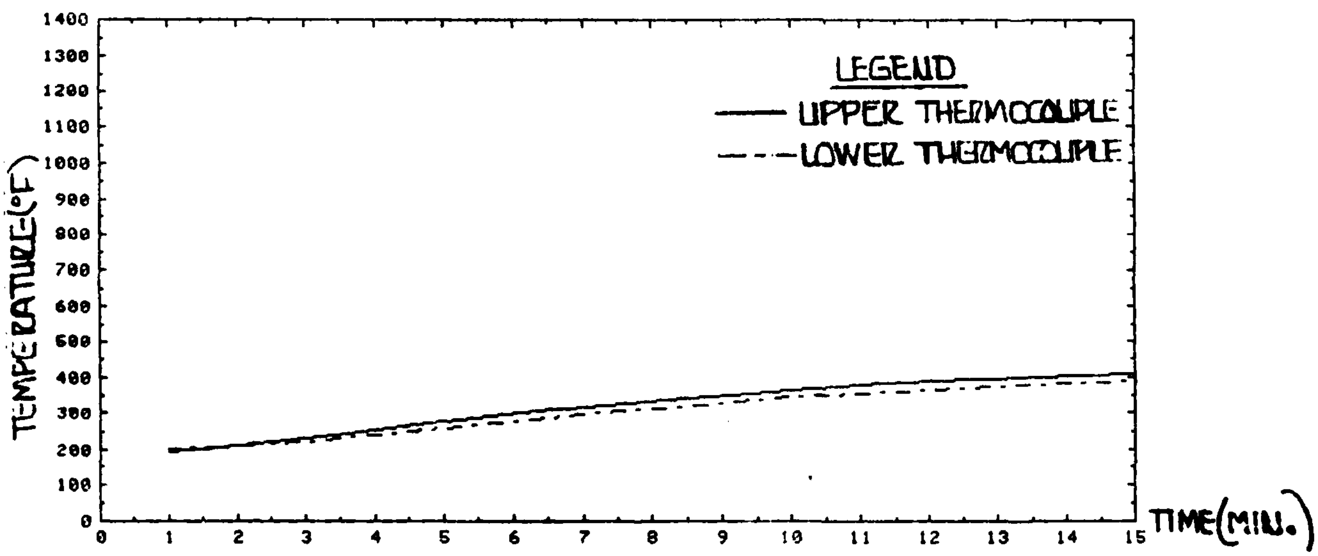

Figure 19. Non-Flame Side Temperature Profile of Flexible Min-K [R] HTS

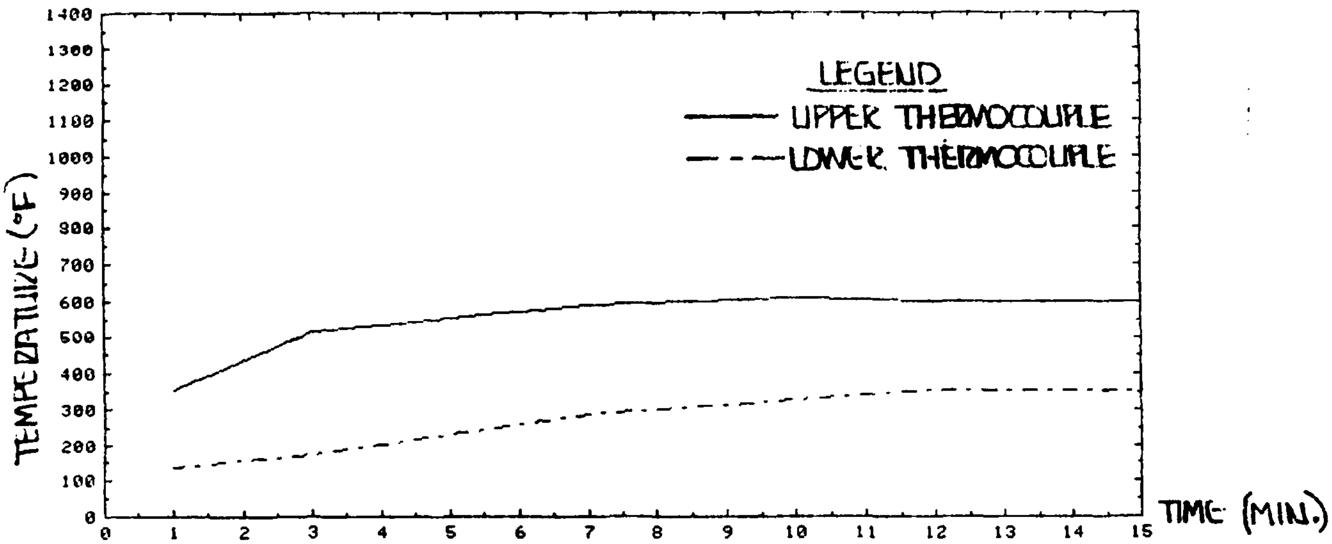

Figure 16. Non-Flame Side Temperature Profile of Nextel[R] 5H-40 Fabric

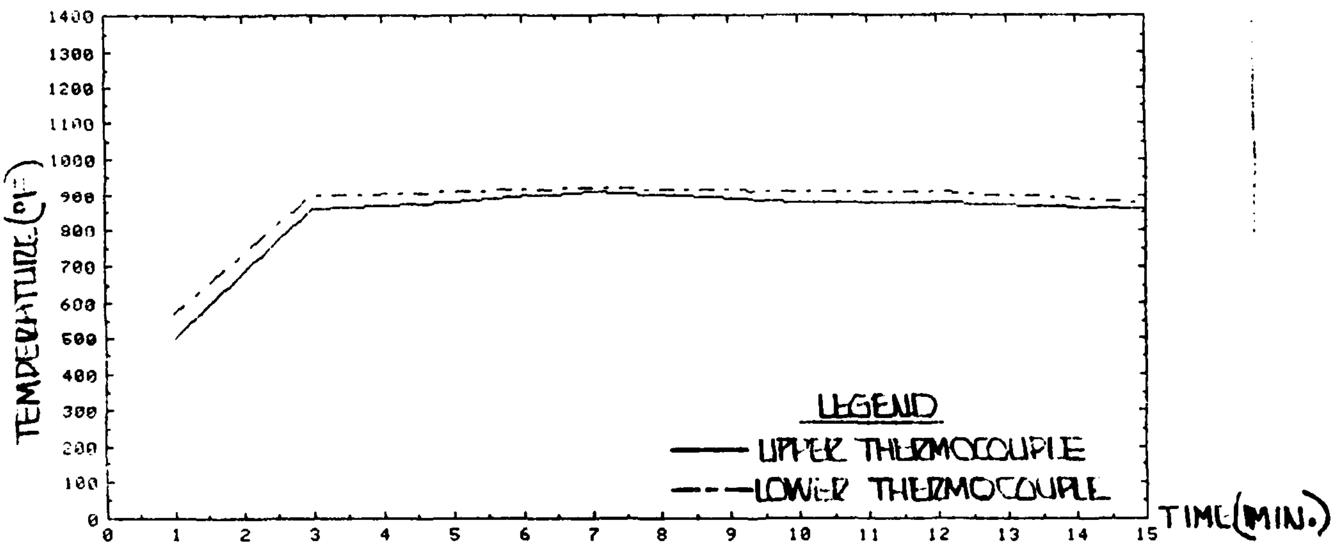

Figure 17. Non-Flame Side Temperature Profile of Vought B

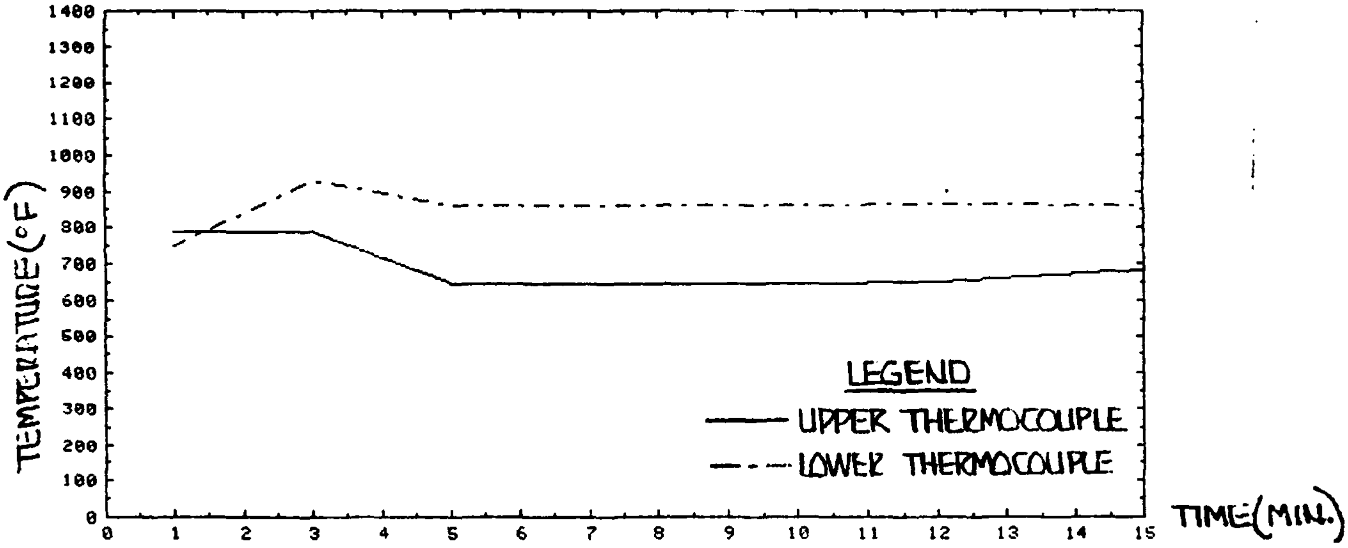

Figure 14. Non-Flame Side Temperature Profile of Nextel R 5H-26 W/Neoprene Coating

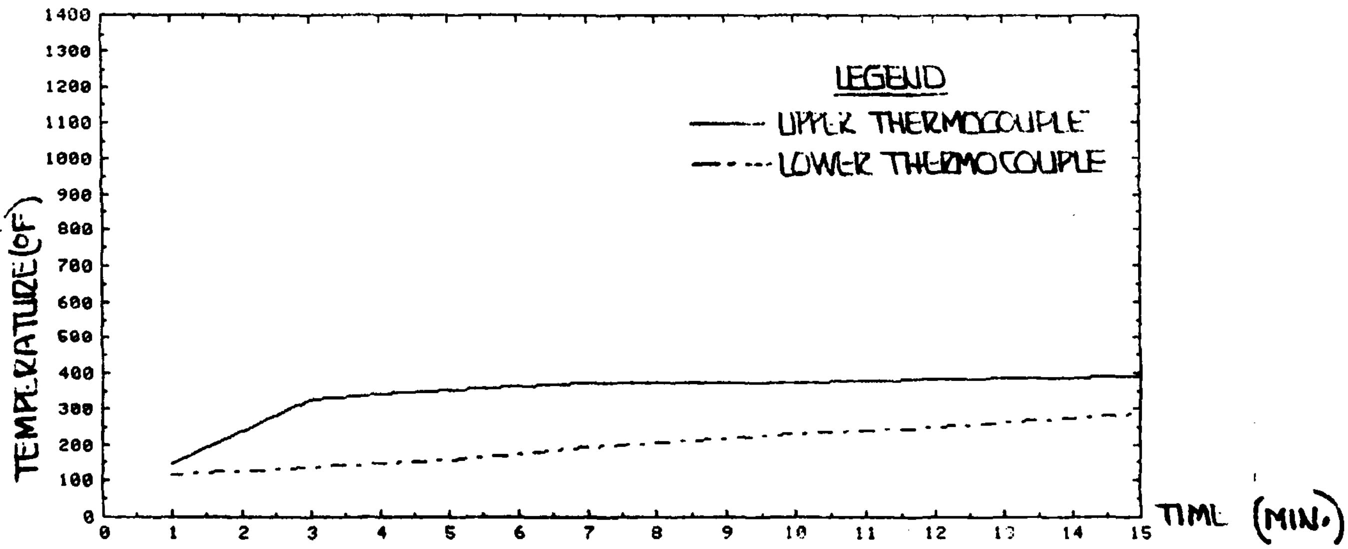

Figure 15. Non-Flame Side Temperature Profile of Nextel R 312 Blanket

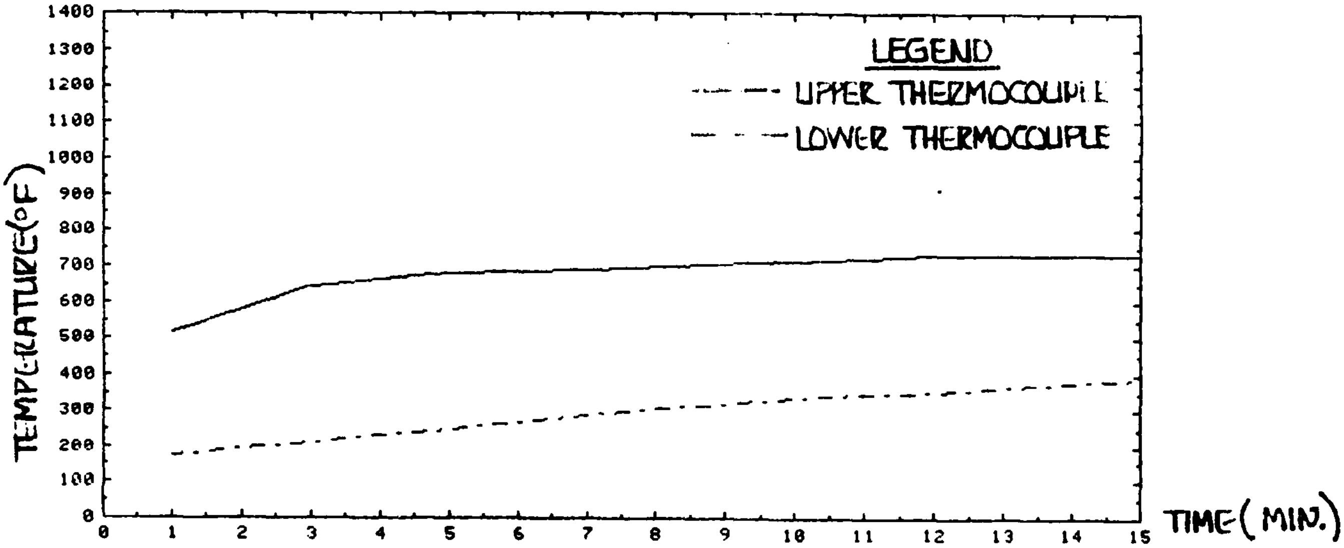

Figure 12. Non-Flame Side Temperature Profile of Nextel R 5H-13 W/Cr_2O_3 Coating

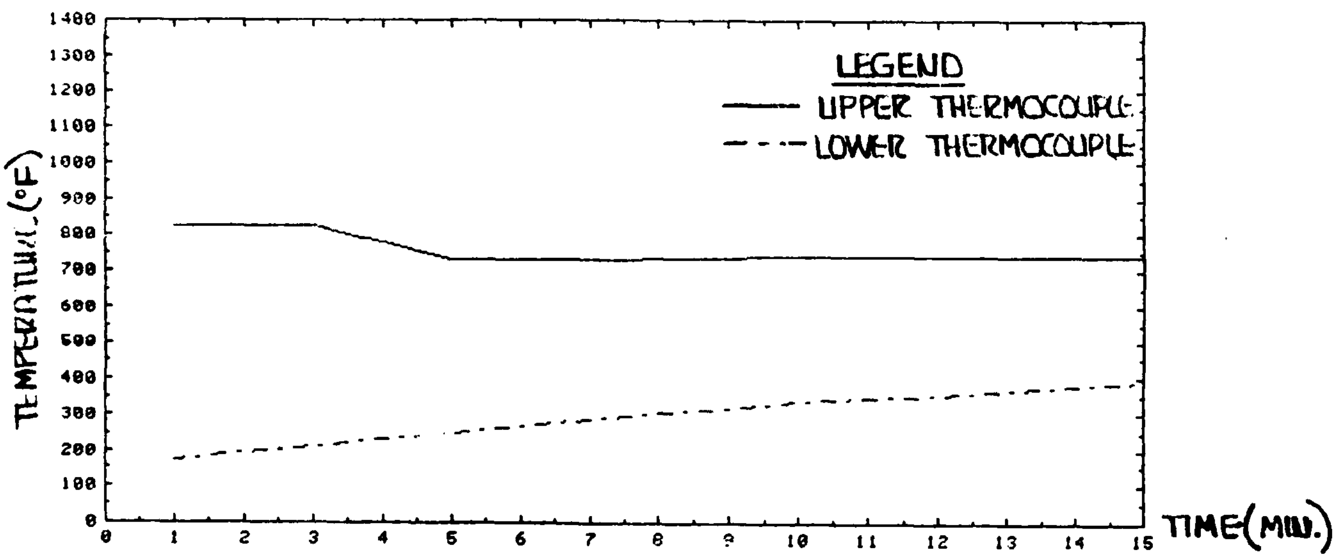

Figure 13. Non-Flame Side Temperature Profile of Nextel R B-10 Fabric W/Aluminized Film

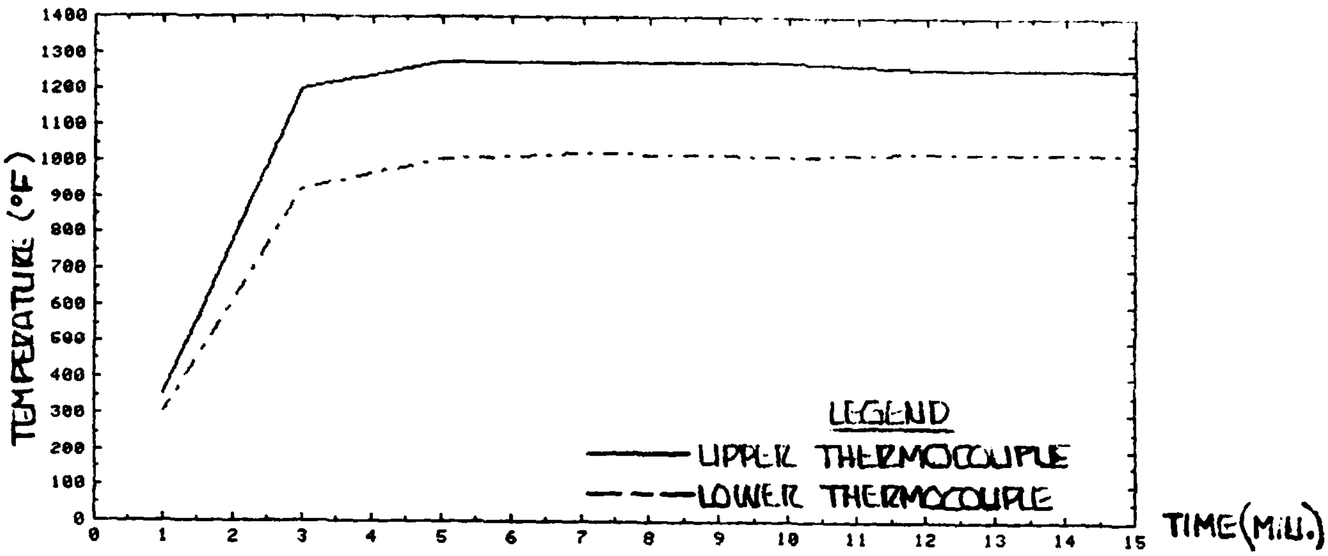

Figure 10. Non-Flame Side Temperature Profile of Nextel R 5H-13 W/AL Panel

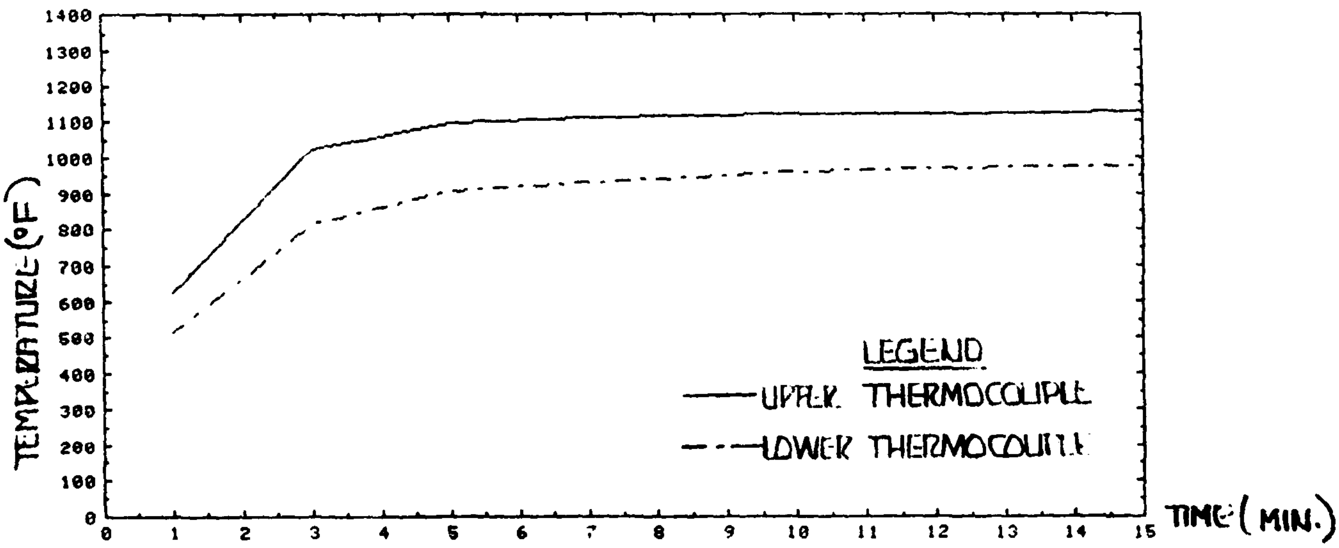

Figure 11. Non-Flame Side Temperature Profile of Nextel R 5H-13 W/Out AL Panel

TABLE 5 (Continued)

PASSING SAMPLES AND MAXIMUM BACKSIDE TEMPERATURES

SAMPLE	MAXIMUM BACKSIDE TEMPERATURE (±5°F)
F-263 Epoxy Resin Composite Firewall 114B-79	572
F-263 Epoxy Resin Composite Firewall 114B-80 with Honeycomb Core	905
F-120 Phenolic Resin Composite Firewall 114B-82 with Honeycomb Core	806
F-825 Phenolic Resin Composite Firewall 114B-85 with Honeycomb Core	716
F-174 Polyimide Resin Composite Firewall 114B-86	716
F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core	599
F-178 BMI Resin Composite Firewall 114B-88	500
F-178 BMI Resin Composite Firewall 114B-89 with Honeycomb Core	644
Boeing Symmetrical Nextel® - Graphite Panel	662
Solimide® BD6F-13	356
Solimide® BD6M-11	338
Solimide® GL8S-180	788
Solimide® BD5M-12	419
F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket	374
F-174 Polyimide Resin Composite Firewall 114B-97 with Filled Honeycomb Core	383
F-174 Polyimide Resin Composite Firewall 114B-98 with Filled Honeycomb Core and Ceramic Blanket	500
K-KARB™	923
K-KARB™ W/Silicon Carbide Infusion	968

TABLE 5

PASSING SAMPLES AND MAXIMUM BACKSIDE TEMPERATURES

SAMPLE	MAXIMUM BACKSIDE TEMPERATURE (±5°F)
DH-242 BRUNSMET[R] Web Insulating Panel	200
INTERAM[R] Brand Fire Barrier CS-195	205
INTERAM[R] Brand Fire Barrier M20 A	675
NEXTEL[R] 5H-13 Fabric	1130
NEXTEL[R] 5H-13 (W/Aluminum Back)	1256
NEXTEL[R] 5H-13 Fabric (W/CR_2O_3 Coating)	734
NEXTEL[R] B-10 Fabric (W/Aluminized Film)	824
NEXTEL[R] 5H-26 Fabric (W/Neoprene Coating)	860
NEXTEL[R] 312 Blanket	392
NEXTEL[R] 5H-40 Fabric	599
NEXTEL[R] 5H-13 (W/Silver Coating)	1391
Vought B	923
Quilite[R]-XS	284
Quilite[R]-XS 758A	356
Flexible Min-K[R] HTS	410
Flexible Min-K[R] HTS 758A	347
Metal Clad SK4242Q	482
Metal Clad SK4242C	464
Eccolite LN1478-39 #2	365
C-G #4530-1	986
C-G #4530-4	896
Fibrelam[R] 3000	824

prevent fire penetration for 15 minutes. Each supplier submitted information on their samples' resistance to water damage and their operating temperature range. Table 6 presents this information.

The thermal protection provided was measured by recording the non-flame side surface temperature of the material. The target maximum temperature to stay below was 700°F. This is approximately the lowest temperatures at which JP-4 has been found to ignite on a hot surface. This is well below the 1100+°F attained by the non-flame side of stainless steel panels.

Table 5 lists those materials which passed the fire test and their maximum non-flame side temperatures. Figures 10 through 35 show the temperature versus time profiles of those materials which also weighed 2.5 pounds or less. In most cases, the temperature rose steadily at first then leveled off toward the end of the test. As can be seen, the lower thermocouple reading is generally lower than the upper thermocouple reading. This can be explained by looking at the test set-up. The flame licks up the sample and therefore a greater amount of heat is transferred to the upper portion of the sample. Other discrepancies between the readings can be attributed to uneven heat dissipation by the samples and varying contact pressures of the probes. The 13 panels which met this 700°F criterion in addition to the weight criterion and passed the fire penetration were ranked using all five areas of evaluation. The remaining panels which passed the fire penetration test were evaluated in all five areas, but were not ranked.

C. Environmental Limitations

Aircraft are exposed to a wide variety of environmental conditions, and, therefore, components such as firewalls must be able to operate properly under these conditions. The conditions include extreme cold temperatures at high altitude, high temperatures from engines, and high humidity from tropical operations. Proper operation for firewalls means maintaining the ability to

TABLE 4 (Continued)

PASSING SAMPLES AND WEIGHTS

SAMPLE	WEIGHT (LB)
38. F-174 Polyimide Resin Composite Firewall 114B-98 with Honeycomb Core and Ceramic Blanket	2.170
39. K-KARB^{TM} Type "C"	N/A
K-KARB^{TM} W/Silicon Carbide Infusion	N/A

N/A NOT AVAILABLE

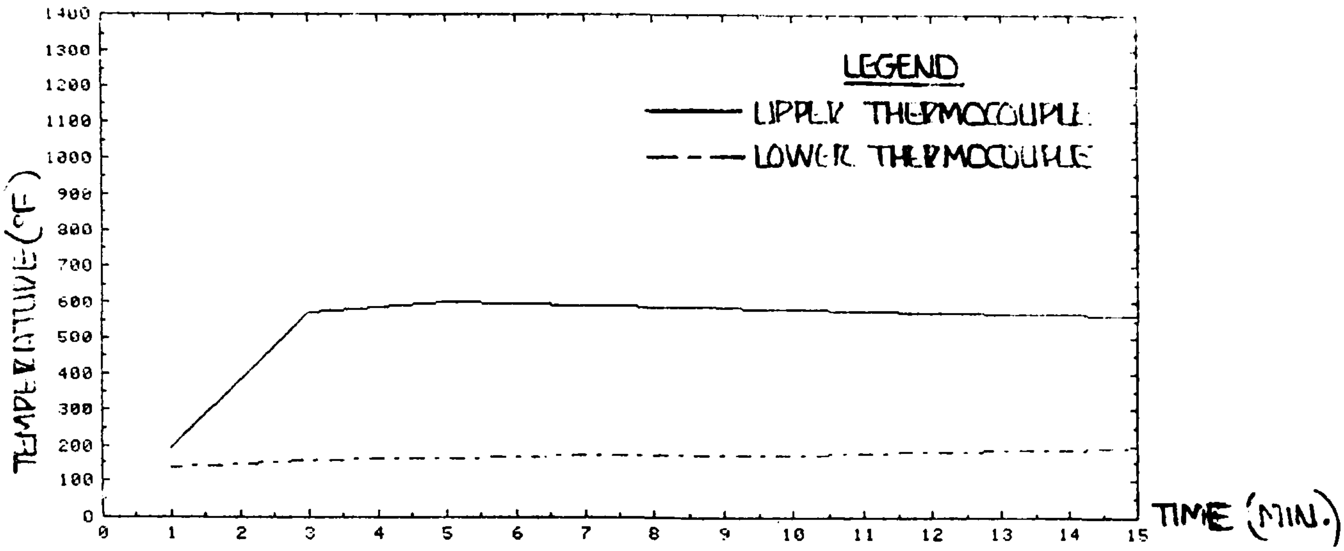

Figure 28. Non-Flame Side Temperature Profile of F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core

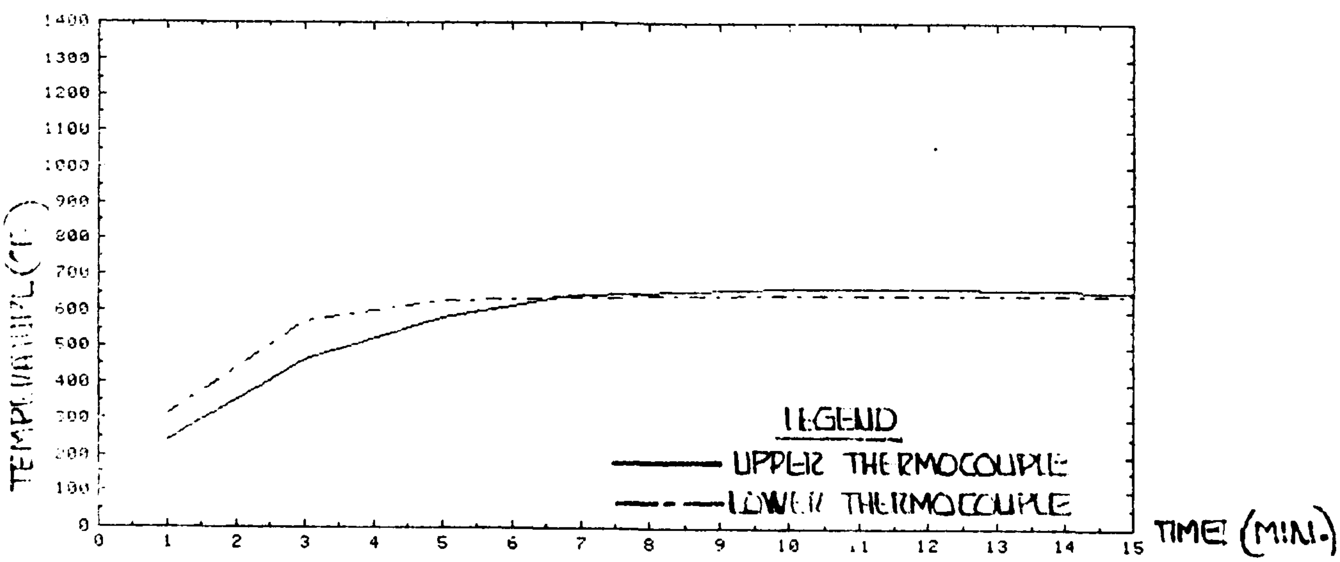

Figure 29. Non-Flame Side Temperature Profile of Boeing Symmetrical Nextel ^{R} - Graphite Panel

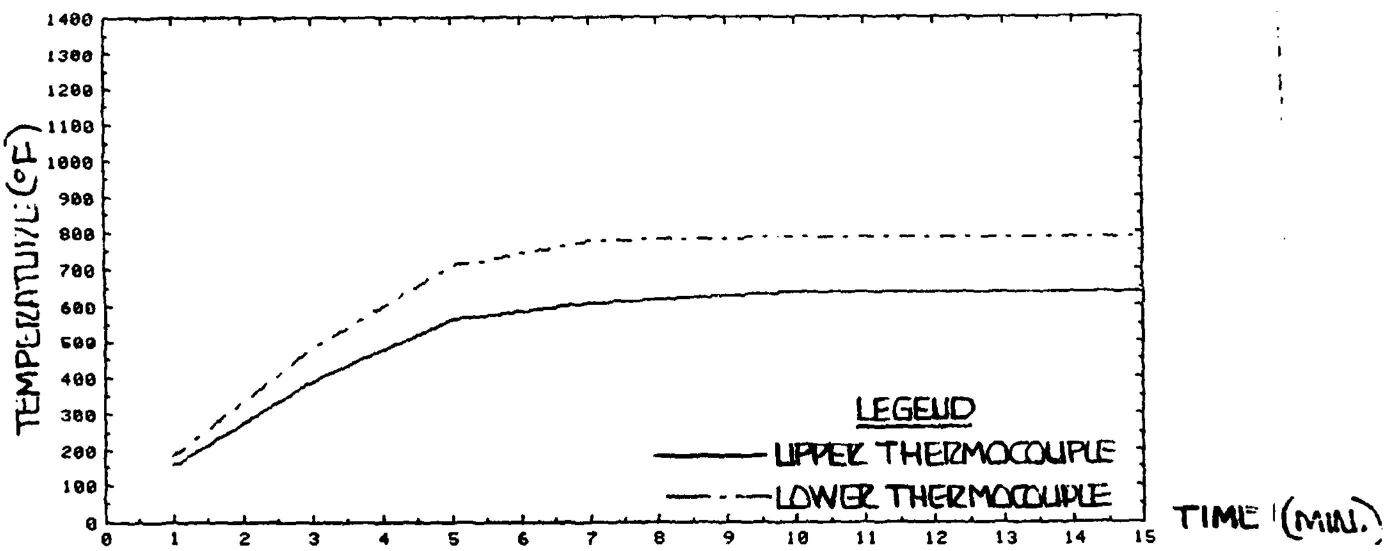

Figure 30. Non-Flame Side Temperature Profile of Solimide R
GL8S-180

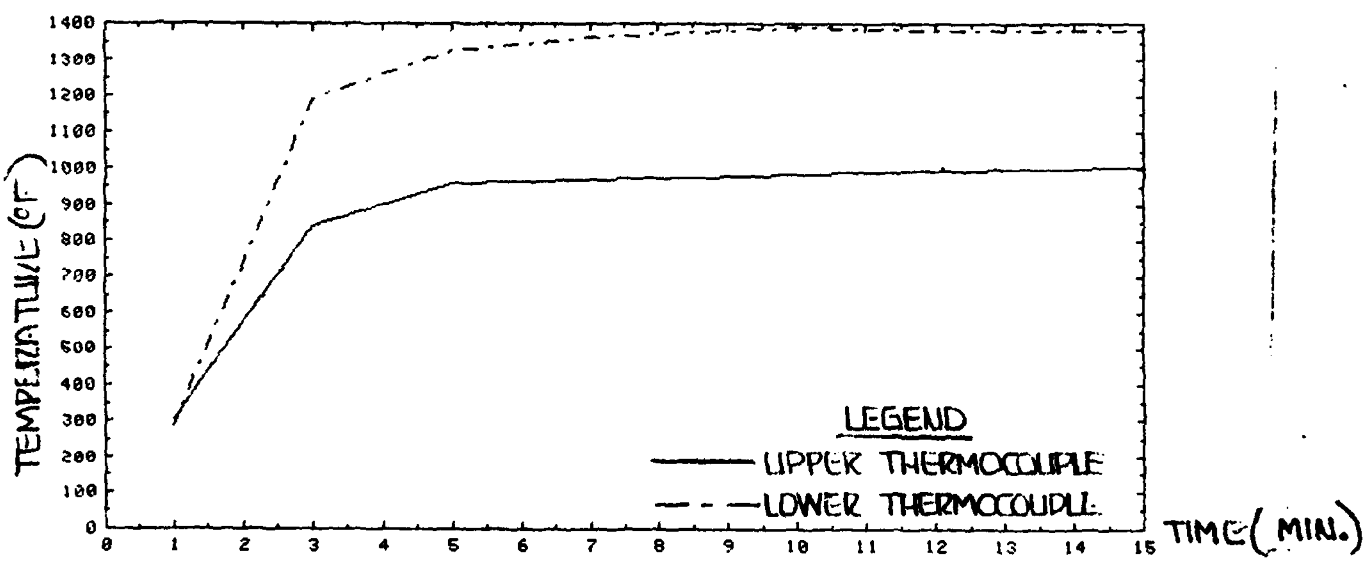

Figure 31. Non-Flame Side Temperature Profile of Nextel R
5H-13 W/Silver Coating

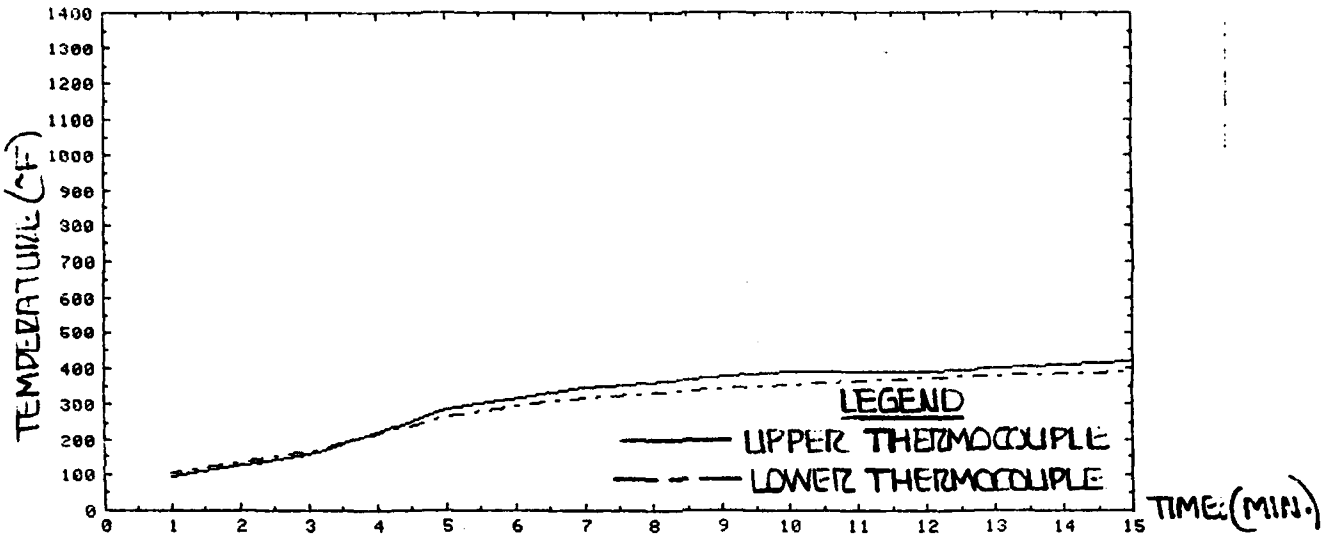

Figure 32. Non-Flame Side Temperature Profile of Solimide R BD5M-12

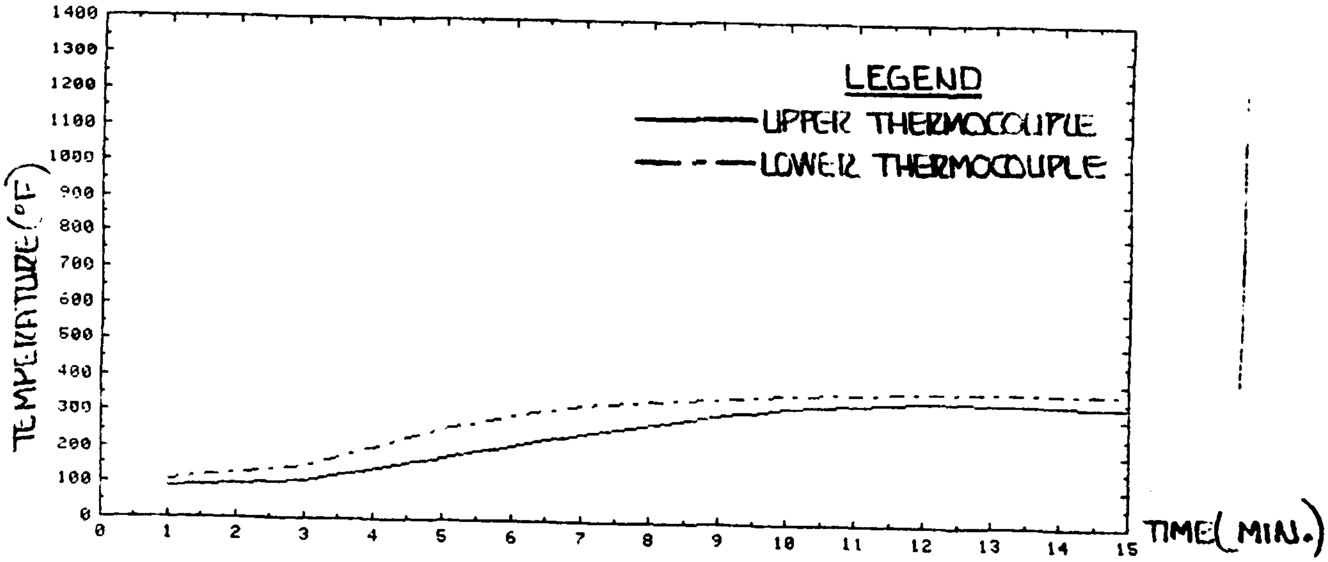

Figure 33. Non-Flame Side Temperature Profile of F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket

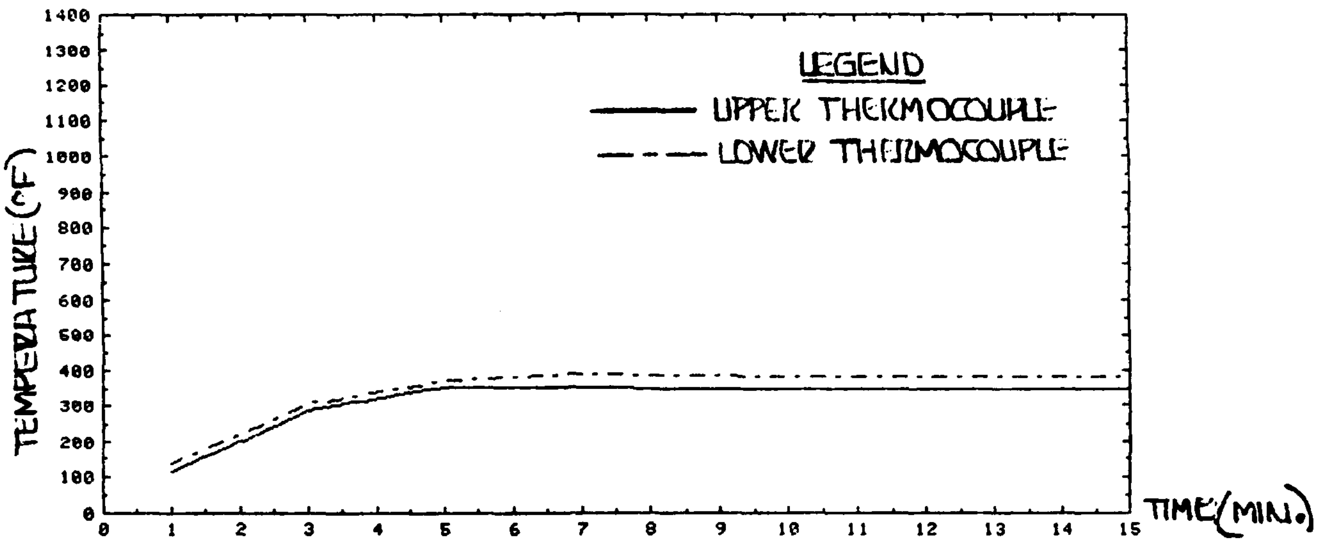

Figure 34. Non-Flame Side Temperature Profile of F-174 Polyimide Resin Composite Firewall 114B-97 with Filled Honeycomb Core

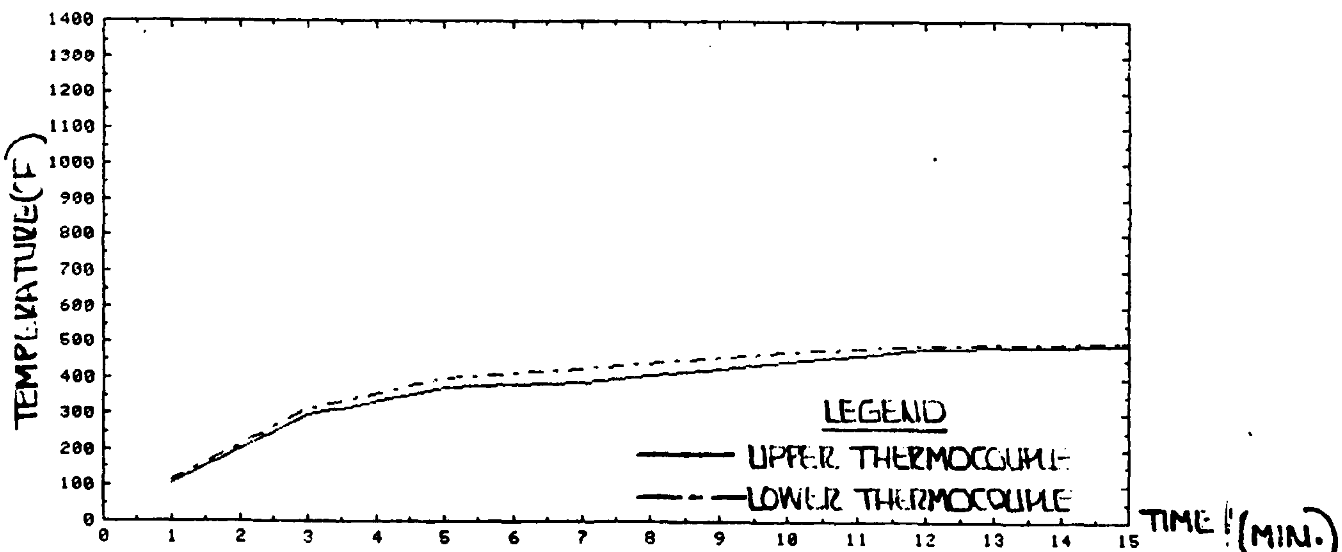

Figure 35. Non-Flame Side Temperature Profile of F-174 Polyimide Resin Composite Firewall 114B-98 with Honeycomb Core and Ceramic

TABLE 6

ENVIRONMENTAL INFORMATION OF PASSING MATERIALS

SAMPLE	TEMP RANGE (°F)	WATER RESISTANCE	FLUID RESISTANCE
DH-242 Brunsmet^R	-200 to 2000	Good	Resistance of insulating materials is poor, but cladding can be designed to improve this.
Interam^R Brand Fire Barrier, CS-195	to 250	Good	Fuel and hydraulic fluid resistance is fair to good. Will reduce expansion of material.
Interam^R Brand Fire Barrier, M20A	to 250	Good	Fuel and hydraulic fluid resistance is fair to good.
Nextel^R 5H-13 Fabric Nextel^R 5H-13 w/Aluminum Back Nextel^R 5H-13 w/Cr_2O_3 Coating Nextel^R 5H-13 w/Silver Coating Nextel^R B-10 w/Aluminized Film Nextel^R 5H-25 w/Neoprene Coating Nextel^R 312 Blanket Nextel^R 5H-40 Fabric	to 2000	Good	Fuel and hydraulic fluids may weaken fibers. Problem can be alleviated by use of coatings such as neoprene, silicone rubber, aluminized film, silver, or Cr_2O_3.
Vought B	N/A	Good	Fuel and hydraulic fluid resistance is good.
Quilite^R-XS	to 1800	Good	Will absorb fluid, but will not degrade material.
Quilite^R-XS 758A	to 1600	Good	Will not absorb fluids.
Flexible Min-K^R HTS	to 1800	Good	Will absorb moisture and fluids, but will not degrade.
Flexible Min-K^R 758A	to 1800	Good	Very good fluid resistance. Will not absorb fluids.

N/A = NOT AVAILABLE

TABLE 6 (Continued)

ENVIRONMENTAL INFORMATION OF PASSING MATERIALS

SAMPLE	TEMP RANGE(°F)	WATER RESISTANCE	FLUID RESISTANCE
Metal Clad SK-4242Q Metal Clad SK-4242C	to 1800	Excellent	Excellent fluid resistance.
Eccolite LN-1478-39 #2	-85 to 500	Excellent	Swells will not dissolve in fuel or hydraulic fluid.
C-G #4530-1	to 700	Good	Should be resistant in both fuel and hydraulic fluids.
Fibrelam[R] 3000			
C-G #4530-4			
Hexcel 114B-79 114B-80	to 350	Poor in high temp high humidity	Adequate can be formulated to meet military specifications.
114B-82 114B-85	to 450	Good	Adequate can be formulated to meet military specifications.
114B-86 114B-87	to 600	Good	Adequate can be formulated to meet military specifications.
114B-88 114B-89	to 600	Good	Adequate can be formulated to meet military specifications.
114B-96 114B-97 114B-98	to 800	Good	Adequate can be formulated to meet military specifications.
Boeing Symmetrical Nextel[R]-Graphite Panel	N/A	N/A	N/A

N/A - NOT APPLICABLE

TABLE 6 (Continued)

AIRCRAFT ENVIRONMENT COMPATIBILITY INFORMATION OF PASSING MATERIALS

Solimide® BD6F-13 Solimide® BD6M-11 Solimide® GL8S-180 Solimide® BD5M-12	to 600	Good	Is not degraded by hydraulic fluids or fuels. Will absorb small amounts due to foam structure.
K-Karb™ K-Karb™ w/Silicon Carbide Infusion	to 800	Good. Will absorb small amounts.	N/A

N/A = NOT AVAILABLE

All of the materials which passed the test can withstand, or can be modified to withstand, the water and other fluids found on an aircraft. However, these modifications might affect the fire test or thermal protection performance, and should be tested before use. The intumescing temperature of 250°F for Interam[R] Brand Fire Barrier severely limits its use in engine nacelles. The Emerson & Cuming, Imi-Tech, and Ciba Geigy samples all had operating temperature ranges ending at or below 700°F. Engine bleed air lines operated at temperatures in excess of this and could shorten the life span of these materials in engine nacelles.

D. Maintenance Requirements

Firewalls may be located in areas where regular maintenance is required and could be subjected to accidental abuse. The two most common forms of abuse are abrasion and banging. The materials used as firewalls must be able to withstand this limited amount of abuse without degrading. If a hole should appear on a firewall, it must be quickly and easily repaired or the firewall replaced. As with environmental areas, each supplier was asked to provide information on the resistance to abrasion and puncture and method of repair. A limited response was received. The information gathered for those materials which passed the fire penetration test is presented in Table 7.

The information supplied by manufacturers was limited and subjective on resistance to damage. Most seemed to think their material would be able to survive minor banging and abrasion. Most of the materials could be attached mechanically or adhesively bonded. Configuration limitations were few. Most samples could be formed into complex shapes during production. Repairs varied from welding patches to curing them in place for composites. All the suppliers noted that their samples could be modified to meet specific requirements without degrading their fire penetration protection by altering the construction and by using coatings.

TABLE 7

MAINTENANCE AND REPAIR REQUIREMENTS OF PASSING MATERIALS

SAMPLE	REQUIREMENTS
DH-242 Brunsmet[R] Web Insulating Panel	Resistance to abrasion dependent on cladding. Material can be mechanically attached or welded. Insulation is repaired by cutting out damaged section and replacing with new piece. Cladding would also have to be replaced by welding a patch. Configurations are limited only by the cladding material.
Interam[R] Brand Fire Barrier, CS-195 Interam[R] Brand Fire Barrier, M20 A	Susceptible to abrasion and puncture without backing. Material can be caulked in place or mechanically attached with backing. Repair can be accomplished by removing damaged area, replacing with new and caulking it into place. Material is flexible and can be made into complex shapes.
Nextel[R] 5H-13 Fabric Nextel[R] 5H-13 W/Aluminum Back Nextel[R] 5H-13 W/CR_2O_3 Coating Nextel[R] 5H-13 W/Silver Coating Nextel[R] B-10 W/Aluminized Film Nextel[R] 5H-26 W/Neoprene Coating Nextel[R] 312 Blanket Nextel[R] 5H-40	Good resistance to abrasion and puncture for ceramic. Strength can be increased by use of coatings such as those listed here. These coatings also improve handling and chemical resistance. Material needs backing for rigidity and so attachment is dependent on backing, Configurations are unlimited. Patches can be hand or machine sewn so repair can be done on the aircraft. Patches can then be coated with whatever panel has on it.
Vought B	Poor resistance to abrasion and puncture. Material can be mechanically fastened or attached by adhesives. Damaged areas can be repaired by riveting a patch in place or replacement of entire panel.
Quilite[R]-XS Quilite[R]-XS 758A	Good resistance to abrasion and puncture for ceramic. This is increased by fire resistant silicone rubber coating. Flexible material can be shaped into a variety of forms. Patches can be sewn in place with ceramic thread. Material can be mechanically attached or adhesively bonded.

N/A - NOT AVAILABLE

TABLE 7 (CONTINUED)

MAINTENANCE AND REPAIR REQUIREMENTS OF PASSING MATERIALS

SAMPLE	REQUIREMENTS
Flexible Min-K^R HTS Flexible Min-K^R HTS 758A	Material is susceptible to abrasion and puncture and should not be used as a structural material. Resistance is increased with protective coatings such as fire resistant silicone rubber. Damaged areas can be cut out and replaced. Material is flexible and can conform to complex shapes.
Metal Clad SK4242Q Metal Clad SK4242C	Metal cladding is 0.003" thick stainless steel foil and has good resistance to abrasion and puncture. Foil is easily repaired. Damaged insulation can be removed and replaced. Can be attached like a steel panel. Limited configuration due to metal cladding.
Eccolite LN-1478-39 #2	N/A
C-G #4530-1 C-G #4530-4 Fibrelam^R 3000	Material damage can be repaired with panel in place for small areas. Specific details are available from Ciba Geigy. Material can be shaped into various forms by two methods; use of adhesives or mechanical attachments is possible. Abrasion and puncture resistance is unknown.
Hexcel 114B-79 114B-80 114B-82 114B-85 114B-86 114B-87 114B-88 114B-89 114B-96 114B-97 114B-98	Material resistance to damage has not been characterized, but can be improved without performance degradation by insertion of Kevlar^R or fiberglass. Resistance to fluids can be increased with coatings of adhesive silicones. Mechanical fasteners are used just as with sheet metal. Damaged areas can be repaired on the aircraft by curing a patch in place or by the use of mechanical fasteners depending on resin system. Can be formed into complex shapes. No limits to configurations.
Boeing Symmetrical Nextel^R-Graphite Panel	

N/A = NOT AVAILABLE

TABLE 7 (Continued)

MAINTENANCE AND REPAIR REQUIREMENTS OF PASSING MATERIALS

SAMPLE	REQUIREMENTS
Solimide^{R} BD6F-13 Solimide^{R} BD6M-11 Solimide^{R} GL8S-180 Solimide^{R} BD5M-12	Material should not be damaged by occasional abuse during maintenance. If repair is necessary, damaged part is cut out and new part is adhesively bonded or mechanically fastened in place. Complex shapes are possible and are limited only by the mold needed to form the panel during curing. This process may be simplified and expand configurations possible. It is also available in tape or sheet form with foil backing.
K-Karb^{R} K-Karb^{R} W/Silicon Carbide Infusion	Material is very strong for graphite and should not be damaged by occasional abuse during maintenance. Patches of the material can be fastened in place with bolts or rivets of same material. Large pieces must be manufactured in a plant. Can be made into compound shapes down to 1/16" thick.

N/A - NOT AVAILABLE

, Ranking

The final phase in this evaluation was ranking those materials which ıssed the fire penetration test, weighed less than 2.5 pounds, and had ɔn-flame side maximum temperatures below 700°F. The ranking is based on the reviously discussed five evaluation areas plus availability of the material, nd acceptability of the configuration tested.

Thirteen samples fell into this group and are ranked in Table 8. The ample Eccolite LN 1478-39 #2 is ranked last for three reasons. First, it is till in the developmental stage and not available commercially. Second, we ound the coating to be easily damaged. Finally, even though the sample assed, after cooling down, a section of the panel fell away indicating the luminum backing had melted and fused with the coating. This means the aximum backside temperature recorded may not have been correct. The Hexcel amples are ranked first because of their overall performance and the company's xperience with aircraft firewall manufacturing. The F-263 epoxy resin panel 'as ranked lower because of its susceptibility to high temperature, high umidity conditions. The metal clad Johns-Manville samples were basically qual. They do not provide a vapor barrier in the configurations tested, but an be made to by the use of coatings or backings. The flexibility of the 3M nd Johns-Manville samples make them excellent choices for subsystem fire ıardening on existing aircraft. The Imi-Tech sample is semi-rigid and can be ıolded to any shape. It would probably need an aluminum back plate for a apor barrier.

In conclusion, these 13 samples provide drastically improved protection and weight savings over existing firewalls. The ranking in Table 8 is geared toward near term use of these materials. All of these materials should be investigated further prior to use as firewalls and fire barriers in aircraft applications.

TABLE 8

RANKING OF PASSING SAMPLES WITH IMPROVED WEIGHT AND THERMAL PROTECTION CHARACTERISTICS

F-174 Polyimide Resin Composite Firewall 114B-97 with filled Honeycomb Core

F-174 Polyimide Resin Composite Firewall 114B-96 with filled Honeycomb Core and S-Glass Blanket

F-174 Polyimide Resin Composite Firewall 114B-98 with filled Honeycomb Core and Ceramic Blanket

F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core

Metal Clad SK4242Q

Metal Clad SK4242C

Solimide[R] BD5M-12

F-263 Epoxy Resin Composite Firewall 114B-79

Nextel[R] 312 Blanket

Quilite[R]-XS

Flexible Min-K[R] HTS

Nextel[R] 5H-40 Fabric

Eccolite LN1478-39 #2

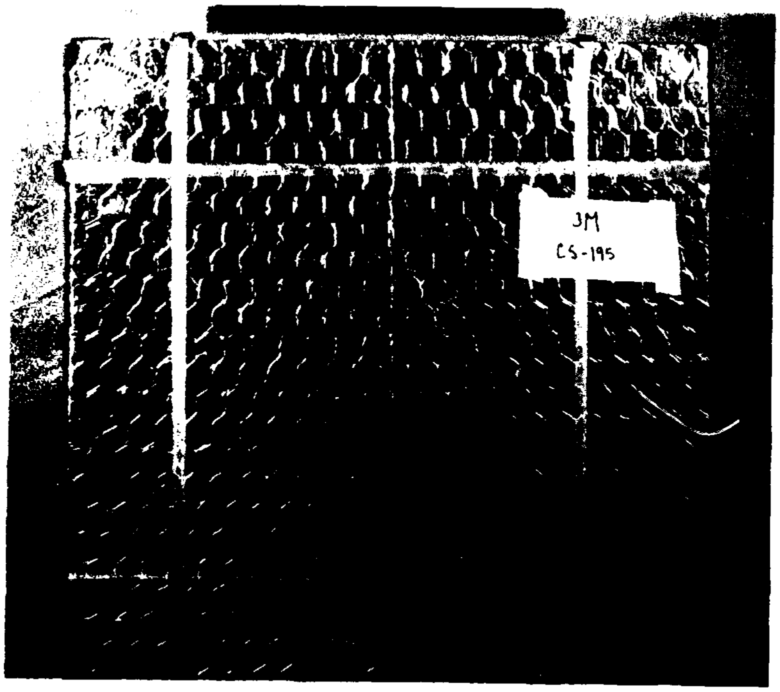

Figure B-3. Interam R Brand Fire Barrier CS-195 Before Fire Penetration Test

Figure B-4. Interam R Brand Fire Barrier CS-195 After Fire Penetration Test

APPENDIX B

BEFORE AND AFTER PHOTOGRAPHS OF PASSING MATERIALS

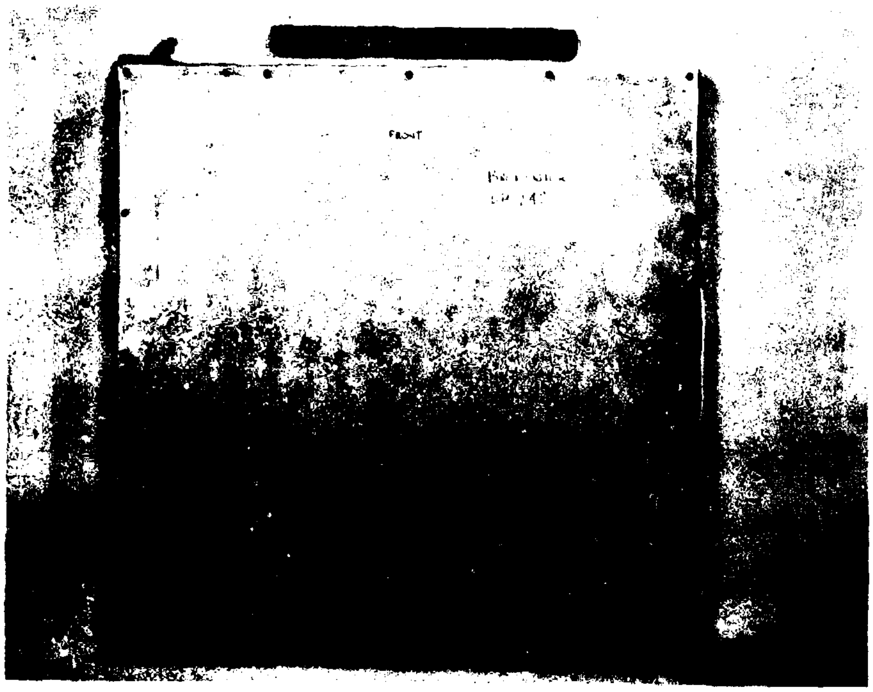

Figure B-1. DH-242 Brunsmet[R] Web Insulating Panel Before Fire Penetration Test

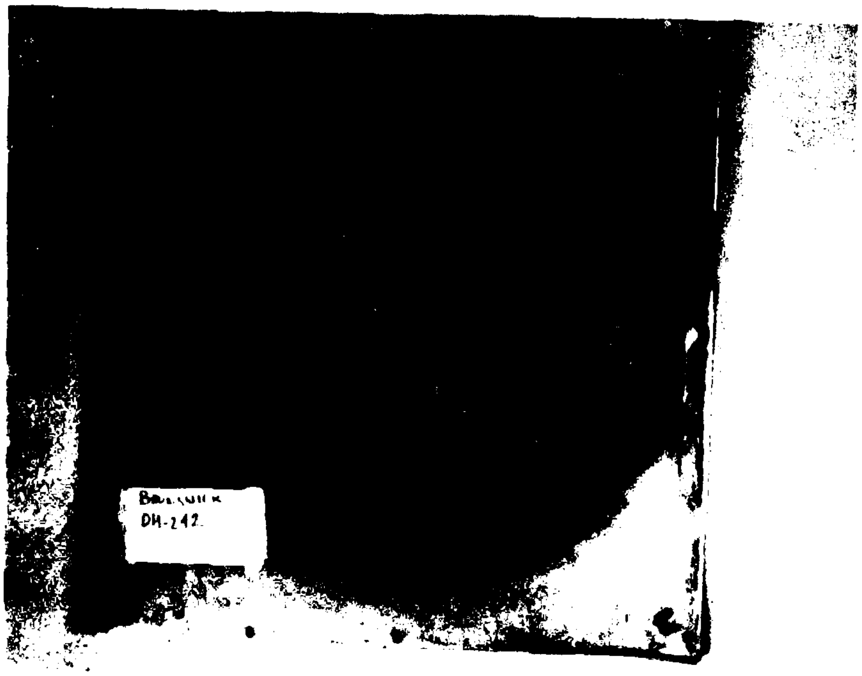

Figure B-2. DH-242 Brunsmet[R] Web Insulating Panel After Fire Penetration Test

TABLE A-2
SAMPLES, PHYSICAL PROPERTIES AND DESCRIPTION - CONTINUED

SAMPLE NAME	CONSTRUCTION	SPECIFIC HEAT C_p (BTU/lb)	THERMAL CONDUCTIVITY K (BTU-in/hr-ft²-°F)	DENSITY P (lb/ft³)	MELT OR DECOMPOSITION TEMPERATURE (°F)	WEIGHT (lb)
Boeing Symmetrical Nextel^R-Graphite panel	Symmetrical Nextel^R Graphite composite panel	N/A	N/A	103.6	3272[2]	1.41
K-Karb^TM	Carbon-carbon composite	N/A	72	91.7	5000	7.64[1]
K-Karb^TM with Silicon Carbide Infusion	Carbon-carbon composite panel with silicon carbide converted surface	N/A	108	91.7	3100	7.64[1]
Solimide^R BD6F-13	Glass fiber-alumina reinforced Solimide^R resin composite panel	N/A	N/A	13.1	600	4.4
Solimide^R BD6M-11	Glass fiber reinforced Solimide^R resin composite panel	N/A	N/A	11.5	600	4.6
Solimide^R BCM-25	Glass fiber-glass microballoon reinforced Solimide^R resin composite panel	N/A	N/A	25.5	600	4.2
Solimide^R GL8S-180	Glass cloth-alumina mat Solimide^R resin composite panel	N/A	N/A	112	600	2.3
Solimide^R BD5M-12	Glass fiber-alumina reinforced Solimide^R resin composite panel	N/A	N/A	12.42	600	2.07
PEEK	Graphite poleyther ether	N/A	N/A	103.2	640	4.3[1]

1 - Estimated weight of 2' x 2' panel
2- Melt temperature of Nextel^R

Note: N/A - Not Availble

TABLE A-2
SAMPLES, PHYSICAL PROPERTIES AND DESCRIPTIONS - CONTINUED

SAMPLE NAME	CONSTRUCTION	SPECIFIC HEAT C_p (BTU/lb-°F)	THERMAL CONDUCTIVITY K (BTU-in/hr-ft²-°F)	DENSITY P (lb/ft³)	MELT OR DECOMPOSITION TEMPERATURE (°F)	WEIGHT (lb)
114B-82, Hexcel Composite Firewall	Graphite-honeycomb core-graphite-ceramic phenolic composite panel	N/A	N/A	N/A	400-600[1]	1.46
114B-84, Hexcel Composite Firewall	Ceramic-graphite-ceramic rubber phenolic composite panel	N/A	N/A	N/A	400-600[1]	1.43
114B-85, Hexcel Composite Firewall	Graphite-honeycomb core-graphite-ceramic rubber phenolic composite panel	N/A	N/A	N/A	400-600[1]	1.47
114B-86, Hexcel Composite Firewall	Graphite-ceramic condensation polyimide composite panel	N/A	N/A	N/A	400-600[1]	0.62
114B-87, Hexcel Composite Firewall	Graphite-honeycomb core-graphite-ceramic condensation polyimide composite panel	N/A	N/A	N/A	400-600[1]	2.48
114B-88, Hexcel Composite Firewall	Graphite-ceramic BMI composite panel	N/A	N/A	N/A	400-600[1]	3.45
114B-89, Hexcel Composite Firewall	Graphite-honeycomb core-graphite ceramic BMI composite panel	N/A	N/A	N/A	400-600[1]	3.12
114B-96, Hexcel Composite Firewall	Graphite-filled honeycomb core-quilted S-Glass blanket composite panel	N/A	N/A	N/A	400-600[1]	2.05
114B-97, Hexcel Composite Firewall	Graphite-filled honeycomb core-graphite ceramic composite panel	N/A	N/A	N/A	400-600[1]	1.97
114B-98, Hexcel Composite Firewall	Graphite-honeycomb core-quilted ceramic blanket composite panel	N/A	N/A	N/A	400-600[1]	1.97

Note: N/A - Not Available   1 - For Resin System

TABLE A-2
SAMPLES, PHYSICAL PROPERTIES AND DESCRIPTIONS - CONTINUED

SAMPLE NAME	CONSTRUCTION	SPECIFIC HEAT C_p (BTU/lb-°F)	THERMAL CONDUCTIVITY K (BTU-in/hr-ft²-°F)	DENSITY P (lb/ft³)	MELT OR DECOMPOSITION TEMPERATURE (°F)	WEIGHT (lb)
691-7	Phenolic F.R.P composite panel	N/A	N/A	N/A	N/A	1.47
691-9	Phenolic F.R.P. composite panel	N/A	N/A	N/A	N/A	0.70
CG-4530-1	Composite face sheets with honeycomb core sandwich panel	N/A	N/A	18.53	700	2.6
Fibrelam[R] Type 1	Composite face sheets with honeycomb core sandwich panel	N/A	N/A	13.42	700	2.8
Fibrelam[R] Type 1 w/Flamarrest[R]	Same as above with one face sheet coated with intumescent	N/A	N/A	15.55	700	3.3
CG-4530-4	Composite face sheets with honeycomb core sandwich panel	N/A	N/A	14.96	700	3.9
Fibrelam[R] 4000 Type 1	Composite face sheets with honeycomb core sandwich panel	N/A	N/A	12.26	700	1.6
Fibrelam[R] 3000	Composite face sheets with honeycomb core sandwich panel	N/A	N/A	2.45	700	2.7
114B-79, Hexcel Composite Firewall	Graphite-ceramic-halogenated epoxy composite panel	N/A	N/A	N/A	350[1]	
114B-80, Hexcel Composite Firewall	Graphite-honeycomb core-graphite-ceramic-halogenated epoxy composite panel	N/A	N/A	N/A	350[1]	2.39
114B-81, Hexcel	Graphite-ceramic-phenolic	N/A	N/A	N/A	400-600[1]	0.54

Note: N/A - Not Available　　1 - For Resin System

TABLE A-2
SAMPLES, PHYSICAL PROPERTIES AND DESCRIPTIONS - CONTINUED

SAMPLE NAME	CONSTRUCTION	SPECIFIC HEAT C_p (BTU/lb-°F)	THERMAL CONDUCTIVITY K (BTU-in/hr-ft²-°F)	DENSITY P (lb/ft³)	MELT OR DECOMPOSITION TEMPERATURE (°F)	WEIGHT (lb)
Flexible Min-K^R HTS	Flexible Min-K^R, edges bound with quartz fabric tape	0.27 (1600°F)	0.51 (1600°F)	16	1800	1.97
Flexible Min-K^R HTS 758A	Same as above, coated with GE fire resistant silicone rubber	0.27 (1600°F)	0.51 (1600°F)	16[1]	1800	3.67
Metal Clad SD4242Q	0.003" stainless steel 3/16" sq dimpled foil around Q-Felt^R insulation	N/A	0.68 (1000°F)	6[1]	2590	1.57
Metal Clad SK4242C	Same as above with Cera-blanket insulation instead of Q-Flet^R	0.27 (2000°F)	2.62 (2000°F)	6[1]	2590	1.70
Eccolite LN 1478-39 #1	Polysiloxane based coating on 0.02" Al sheet	N/A	N/A	N/A	500	1.72
Eccolite LN 1478-39 #2	Polysiloxane based coating on 0.02" Al sheet	N/A	N/A	N/A	500	2.06
Eccolite LN 1478-40	Polysiloxane based coating on 0.02" Al sheet	N/A	N/A	N/A	500	2.40
691-1	Phenolic F.R.P. - glass fiber reinforced composite panel	N/A	N/A	N/A	N/A	1.43
691-2	Phenolic F.R.P. - glass fiber reinforced composite panel	N/A	N/A	N/A	N/A	1.59
691-4	Phenolic F.R.P. - glass fiber reinforced composite panel	N/A	N/A	N/A	N/A	1.51
691-5	Phenolic F.R.P. - glass fiber reinforced composite panel	N/A	N/A	N/A	N/A	1.53
691-6	Pherolic F.R.P. - glass fiber reinforced composite panel	N/A	N/A	N/A	N/A	1.38

1 Density of insulation

Note: N/A - Not Available

TABLE A-2
SAMPLES, PHYSICAL PROPERTIES AND DESCRIPTIONS - CONTINUED

SAMPLE NAME	CONSTRUCTION	SPECIFIC HEAT C_p (BTU/lb°F)	THERMAL CONDUCTIVITY K (BTU-in/hr-ft^2-°F)	DENSITY P (lb/ft^3)	MELT OR DECOMPOSITION TEMPERATURE (°F)	WEIGHT (lb)
Foamega	Silicone Foam Sheet	N/A	0.43 (70°F)	15	400	2
Vought A	Carbon-Carbon Composite	0.387	N/A	100	5000	1.17
Vought B	Carbon-Carbon Composite	0.387	N/A	100	5000	1.17
Vought C	Carbon-Carbon Composite	0.387	N/A	100	5000	1.17
E6052-77-1 Dow Corning^R	Silicone elastomer press	0.3	1.5	91	450	1.94
E6052-77-2 Dow Corning^R	Silicone elastomer press molded onto 0.02" Al sheet	0.3	1.5	72	450	2.17
E6052-77-3 Dow Corning^R	Silicone elastomer press molded onto 0.02" Al sheet	0.3	1.5	91	450	2.8
E6173-31-1 Dow Corning^R	Silicone elastomer press molded onto 0.02" Al sheet	N/A	N/A	N/A	450	3.14
E6173-31-2 Dow Corning^R	Silicone elastomer press molded onto 0.02" Al sheet	N/A	N/A	N/A	450	2.36
Dow Corning^R X35800	Elastomeric coating on 0.02" Al sheet	0.33	0.52	24.3	N/A	3.0
Dow Corning^R X35066	Elastomeric coating on 0.02" Al sheet	0.33	0.52	26.3	N/A	3.0
Quilite^R-XS	Quilted blanket of Nextel^R Q-Felt^R insulation and S-Glass cloth	N/A	0.68 (1000°F)	6[1]	3272[2]	1.06
Quilite^R-XS 758A	Same as above, coated with GE fire resistant silicone rubber	N/A	0.68 (1000°F)	6[1]	3272[2]	3.51

1 Density of insulation
2 Melt temperature of Nextel^R cloth

Note: N/A Not Available

TABLE A-2
SAMPLES, PHYSICAL PROPERTIES AND DESCRIPTIONS

SAMPLE NAME	CONSTRUCTION	SPECIFIC HEAT C_p (BTU/lb°F)	THERMAL CONDUCTIVITY K (BTU-in/hr-ft^2-°F)	DENSITY P (lb/ft^3)	MELT OR DECOMPOSITION TEMPERATURE (°F)	WEIGHT (lb)
DH-242 Brunsmet® Web Insulating Panel	Metal fiber insulation behind 0.012" 304 stainless steel	N/A	0.42 (70°F)	0.9125	2500-2600	6.41
Nor*Fab 800 Fabric 28HT 110 Plain	Woven fabric of PBI and Refrosil fibers W/Al backing	N/A	0.64 (70°F)	3.1	1040 3100	0.78
Interam® Brand Fire Barrier,CS-195	Instumescent panel w/chicken wire and al foil on one and stainless steel backing	0.302 (1650°F)	0.66 (1130°F)	95	250	11
Interam® Brand Fire Barrier, M20A	Intumescent matting	0.265 (1650°F)	1.13 (1200°F)	39	250	5.04
Nextel® 5H-13 Fabric w/silicone rubber coating	Ceramic Fabric coated with silicone rubber	0.3 (1850°F)	0.94 (1850°F)	56	3272	0.6
Nextel® 5H-13 Fabric w/CR_2O_3 coating	Ceramic Fabric coated with Cr_2O_3	0.3 (1850°F)	0.94 (1850°F)	58	3272	0.25
Nextel® B-10 Fabric w/aluminized film	Ceramic Fabric with aluminum film	0.3 (1850°F)	0.94 (1850°F)	61	3272	0.25
Nextel® 5H-26 Fabric w/neoprene coating	Ceramic Fabric with neoprene coating	0.3 (1850°F)	0.94 (1850°F)	70	3272	1.0
Nextel® Blanket	B-10 Fabric quilted with 1/8" thick Q-Felt® insulation	0.3 (1850°F)	0.6 (1850°F)	15	3272	1.0
Nextel® 5H-40 Fabric	Ceramic Fabric	0.3 (1850°F)	1.6 (1850°F)	53	3272	0.7
Nextel® 5H-13 Fabric w/silver coating	Ceramic Fabric Coated with silver	0.3 (1850°F)	0.94 (1850°F)	43	3272	0.35

Note: N/A - Not Available

TABLE A-1 (Continued)
Samples and Suppliers

SUPPLIER	SUPPLIER NAME
	F-178 BMI Resin Composite Firewall 114B-88
	F-178 BMI Resin Composite Fire-wall 114B-89 with Honeycomb Core
	F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket
	F-174 Polyimide Resin Composite Firewall 114B-97 with Filled Honeycomb Core
	F-174 Polyimide Resin Composite Firewall 114B-98 with Honeycomb Core and Ceramic Blanket
Boeing Commercial Airplane Company	Symmetrical Nextel^{R}-Graphite Panel
Kaiser Aerotech	K-Karb^{TM}
	K-Karb^{TM} W/Silicon Carbide Infusion
Imi-Tech	Solimide^{R} BD6F-13
	Solimide^{R} BD6M-11
	Solimide^{R} GL8S-180
	Solimide^{R} BD5M-12
	Solimide^{R} BCM-25
Imperial Chemical Industries PLC	PEEK Graphite Composite Panel

TABLE A-1 (Continued)

Samples and Suppliers

SUPPLIER	SAMPLE NAME
Ciba-Geigy Plastics and Additives Company	C-G #4530-1
	Fibrelam[R] Type 1
	Fibrelam[R] Type 1 W/Flamarrest[R]
	C-G #4530-4
	Fibrelam[R] 4000 Type 1
	Fibrelam[R] 3000
Hexcel	F-263 Epoxy Resin Composite Firewall 114B-79
	F-263 Epoxy Resin Composite Firewall 114B-80 with Honey-comb Core
	F-120 Phenolic Resin Composite Firewall 114B-81
	F-120 Phenolic Resin Composite Firewall 114B-82 with Honey-comb Core
	F-825 Phenolic Resin Composite Firewall 114B-84
	F-825 Phenolic Resin Composite Firewall 114B-85 with Honey-comb Core
	F-174 Polyimide Resin Composite Firewall 114B-86
	F-174 Polyimide Resin Composite Firewall 114B-87 with Honey-comb Core

TABLE A-1 (Continued)

SAMPLES AND SUPPLIERS

SUPPLIER	SAMPLE NAME
Dow Corning	Dow Corning[R] E6052-77-1
	Dow Corning[R] E6052-77-2
	Dow Corning[R] E6052-77-3
	Dow Corning[R] E6173-31-1
	Dow Corning[R] E6173-31-2
	Dow Corning[R] X35800
	Dow Corning[R] X35066
Johns-Manville	Quilite[R]-XS
	Quilite[R]-XS 758A
	Flexible Min-K[R] HTS
	Flexible Min-K[R] HTS 758A
	Metal Clad SK4242Q
	Metal Clad SK4242C
Emerson & Cuming	Eccolite LN 1478-39 #1
	Eccolite LN 1478-39 #2
	Eccolite LN 1478-40
	691-1
	691-2
	691-4
	691-5
	691-6
	691-7
	691-9

TABLE A-1

SAMPLES AND SUPPLIERS

SUPPLIER	SAMPLE NAME
Brunswick Technetics	DH242 BRUNSMET^R Web Insulating Panel
Amatex Corporation	Nor*Fab 800 Fabric 28HT 110 Plain
3M	Interam^R Brand Fire Barrier CS-195
	Interam^R Brand Fire Barrier M20A
	Nextel^R 5H-13 Fabric
	Nextel^R 5H-13 Fabric W/Silicone Rubber Coating
	Nextel^R 5H-13 Fabric W/CR_2O_3 Coating
	Nextel^R B-10 Fabric W/Aluminized Film
	Nextel^R 5H-26 Fabric W/Neoprene Coating
	Nextel^R 312 Blanket
	Nextel^R 5H-40 Fabric
	Nextel^R 5H-13 W/Silver Coating
Bisco Products, Inc.	Foamega
Vought Corporation	Vought A
	Vought B
	Vought C

APPENDIX A

SAMPLE DESCRIPTIONS

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. The samples listed in Table 8 passed the Air Force fire penetration test and provide weight savings and increased thermal protection over existing firewalls.

2. The oil burner flame proved to be a more severe flame than the propane torch flame.

3. The Fire Test Shelter provides a safe, controllable environment for conducting fire penetration tests.

B. Recommendations

1. The aforementioned materials should be considered for use as firewalls and fire hardening materials on aircraft.

2. Analytical studies should be conducted to provide screening procedures for materials suggested as firewalls.

3. All materials suggested to be used as firewalls should be subjected to the fire penetration test using the oil burner flame source.

4. The materials which passed this testing should be subjected to further testing in other than flat panel configurations to determine other areas of use.

Figure B-5. Interam R Brand Fire Barrier M20A Before Fire Penetration Test

Figure B-6. Interam R Brand Fire Barrier M20A After Fire Penetration Test

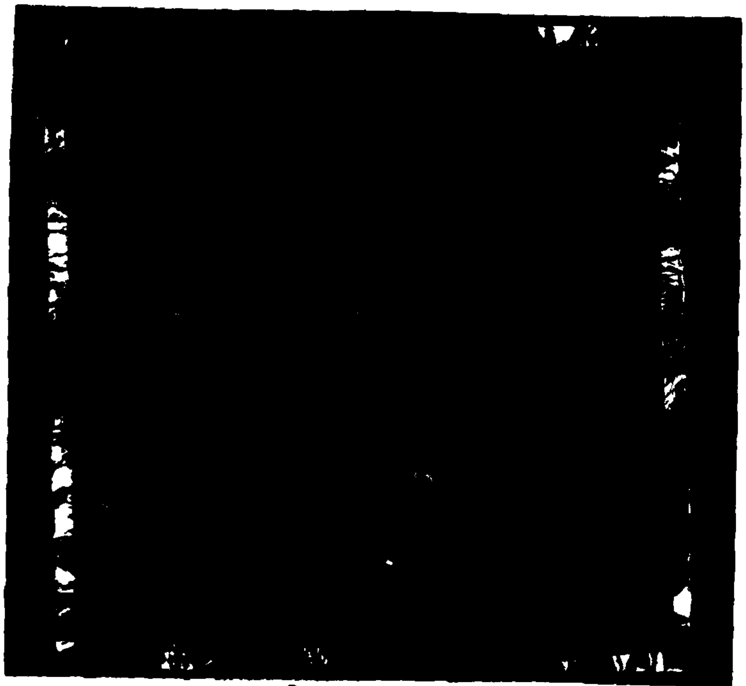

Figure B-7. Nextel R 5H-13 Fabric Without Aluminum Back Before Fire Penetration Test

Figure B-8. Nextel R 5H-13 Fabric Without Aluminum Back After Fire Penetration Test

*Figure B-9. Nextel R 5H-1[illegible] with Aluminum Back After Fire Penetration Test

Figure B-1[illegible]. Nex[illegible] with [illegible] Coatin[illegible] Fire [illegible]ation Test

*NOTE: Pictu[illegible] Available

*Figure B-11. Nextel[R] B-10 Fabric with Aluminized Film After Fire Penetration Test

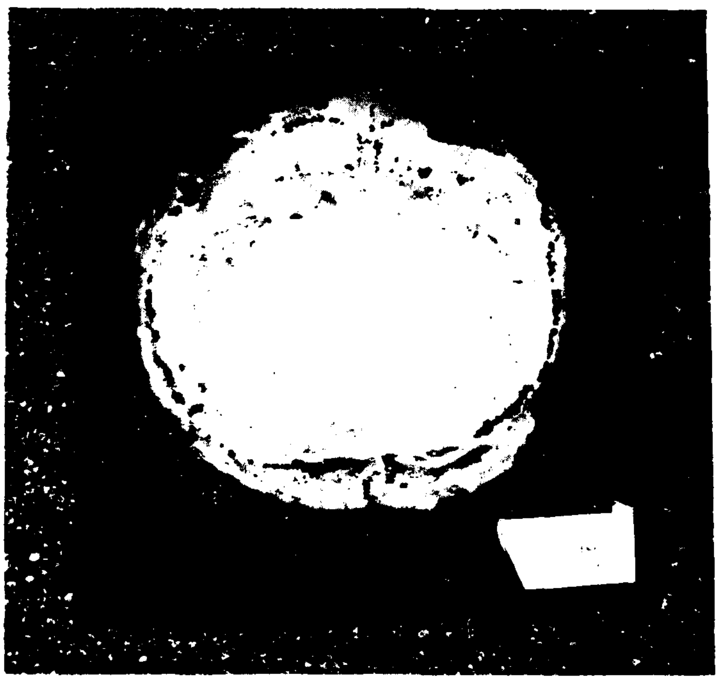

*Figure B-12. Nextel[R] 5H-26 Fabric with Neoprene Coating After Fire Penetration Test

*NOTE: Picture of Sample Before Test not Available

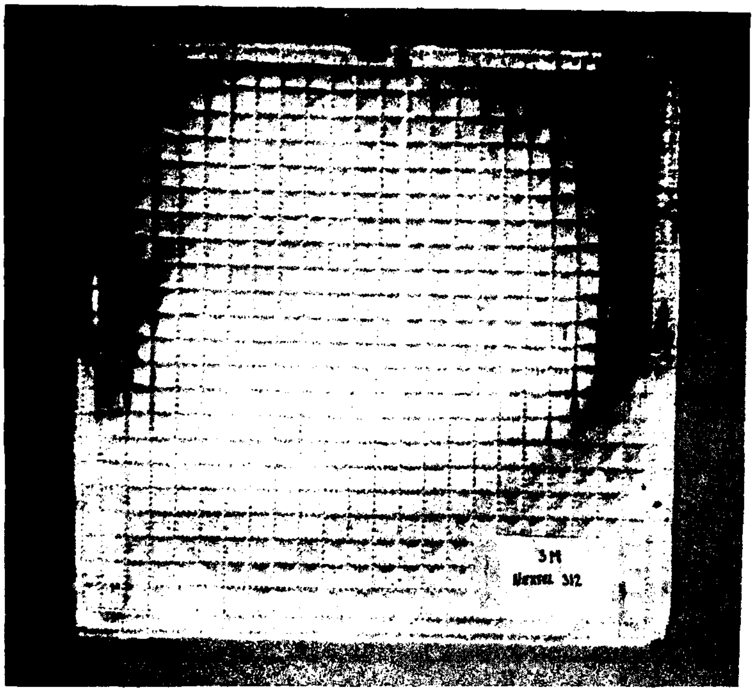

*Figure B-13. Nextel [R] 312 Blanket After Fire Penetration Test

*Figure B-14. Nextel [R] 5H-40 Fabric After Fire Penetration Test

*NOTE: Picture of Sample Before Test Not Available

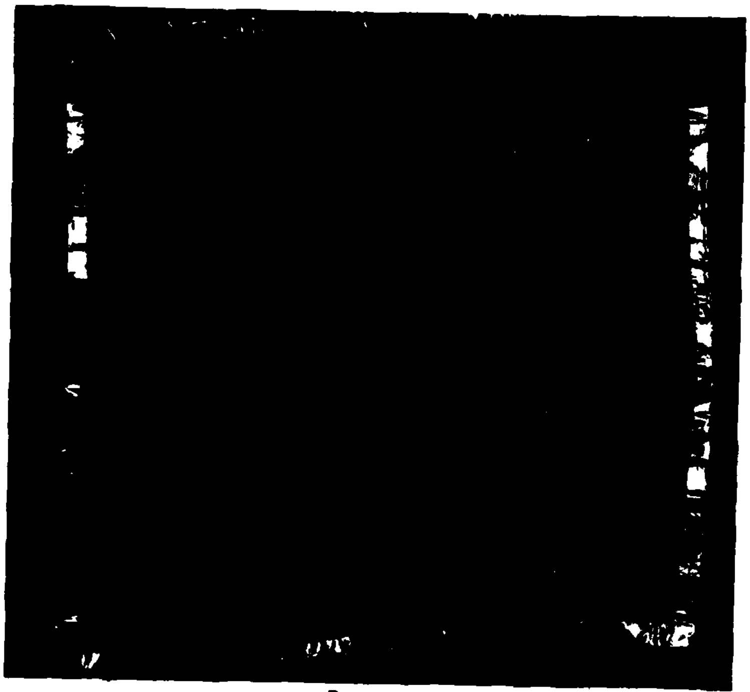

Figure B-15. Nextel[R] 5H-13 with Silver Coating Before Fire Penetration Test

Figure B-16. Nextel[R] 5H-13 with Silver Coating After Fire Penetration Test

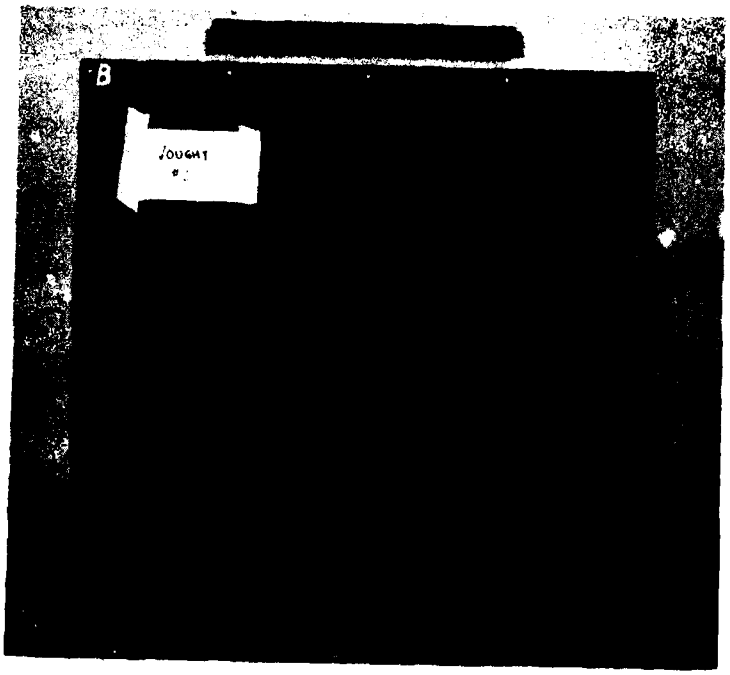

Figure B-17. Vought B Before Fire
Penetration Test

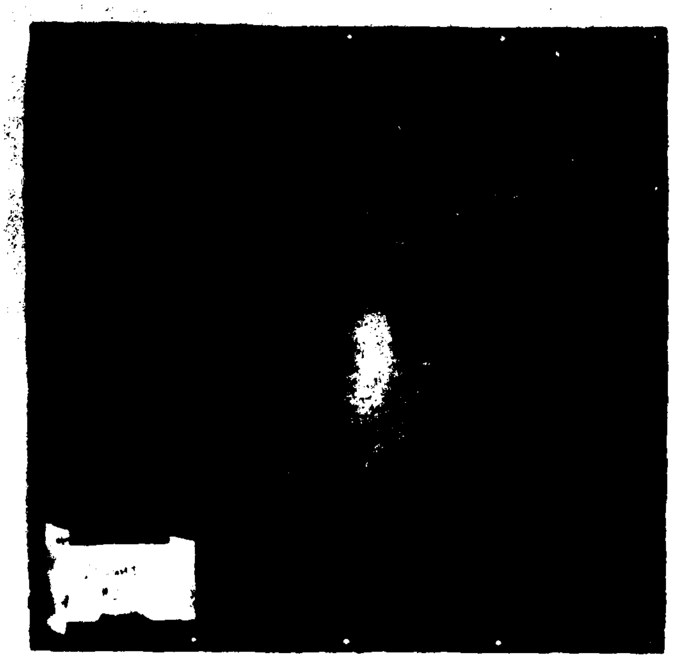

Figure B-18. Vought B After Fire
Penetration Test

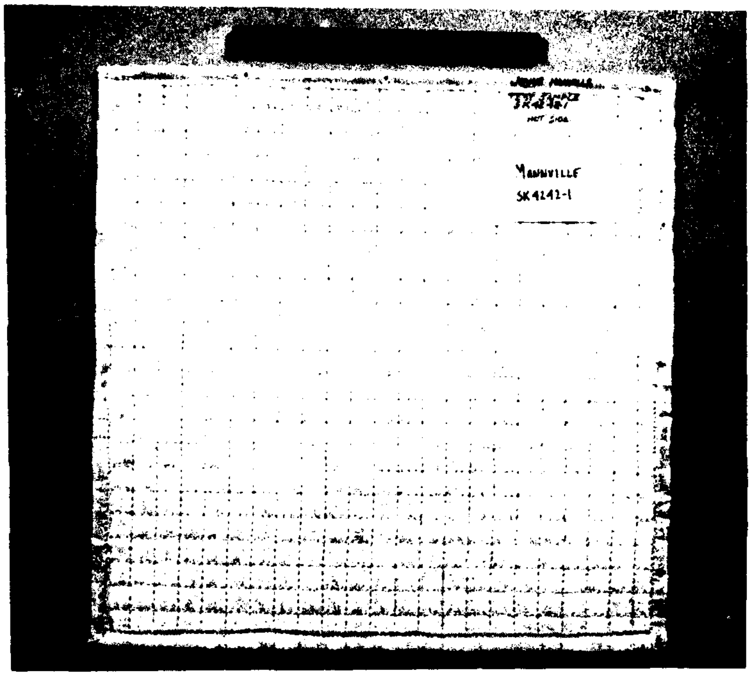

Figure B-19. Quilite^R-XS Before Fire Penetration Test

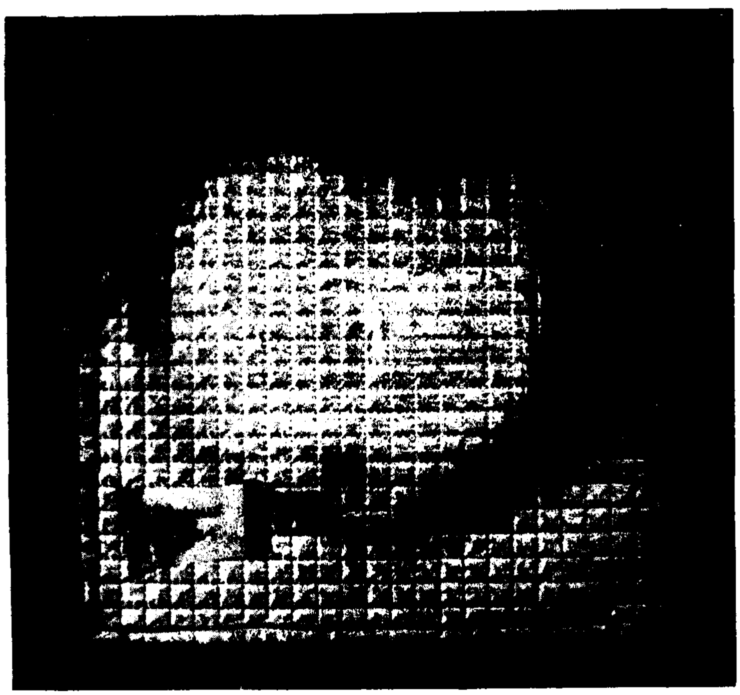

Figure B-20. Quilite^R-XS After Fire Penetration Test

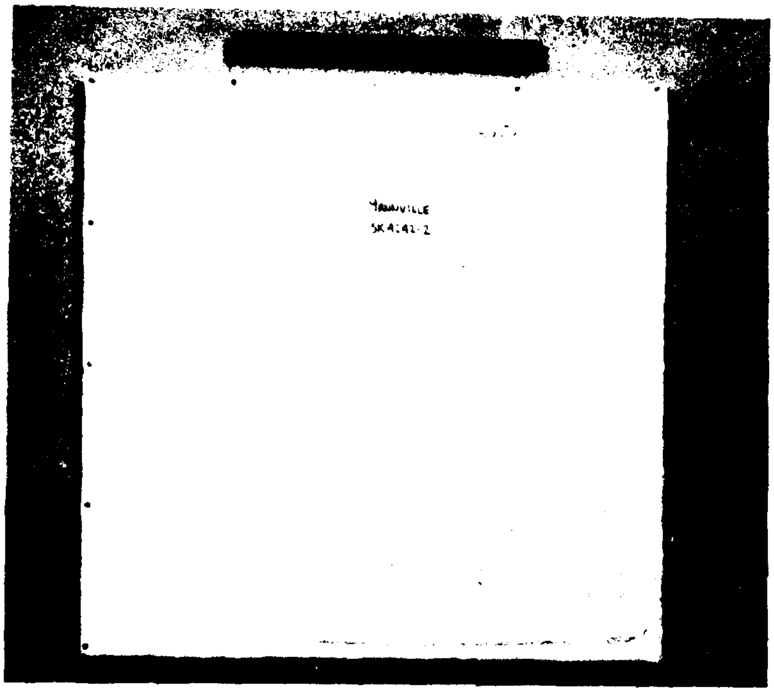

Figure B-21. Quilite^{R}-XS 758A Before Fire Penetration Test

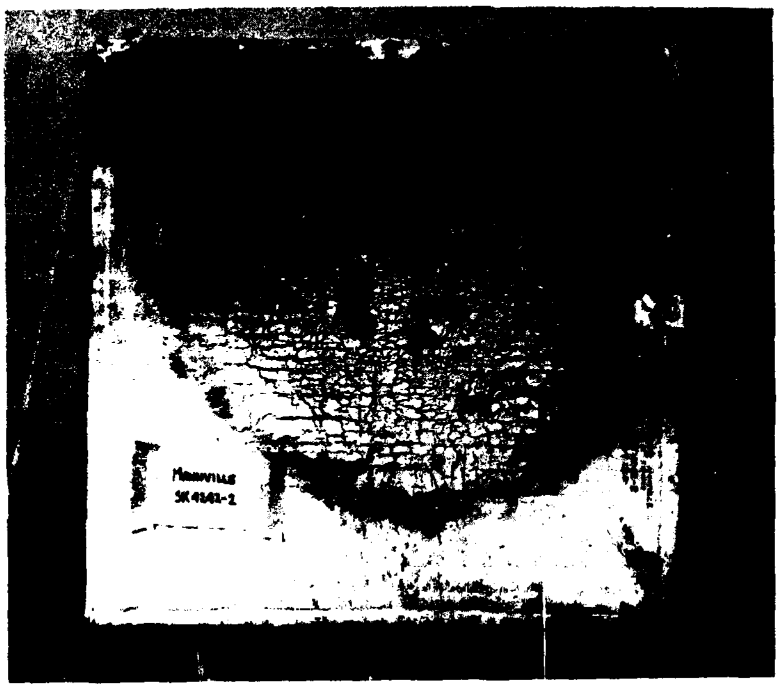

Figure B-22. Quilite^{R}-XS 758A After Fire Penetration Test

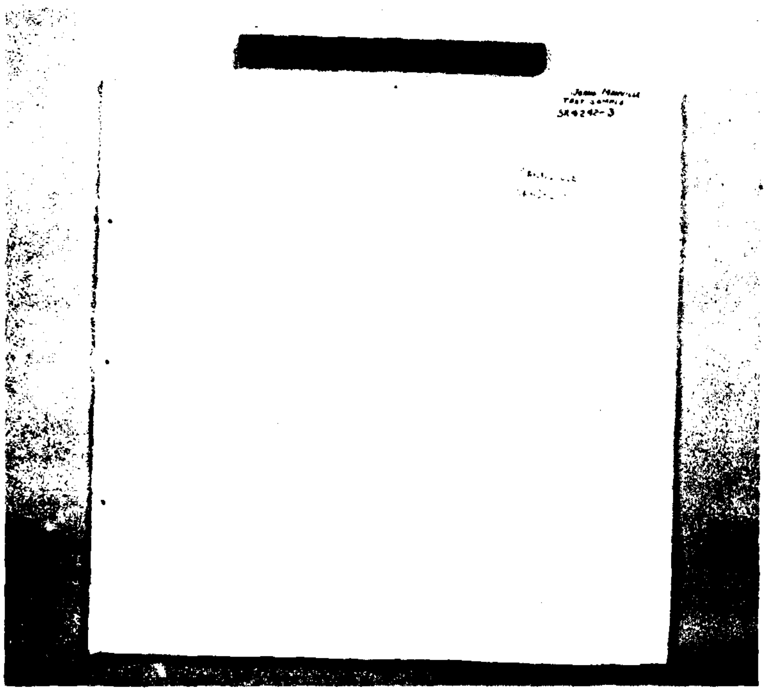

Figure B-23. Flexible Min-K^{R} HTS Before Fire Penetration Test

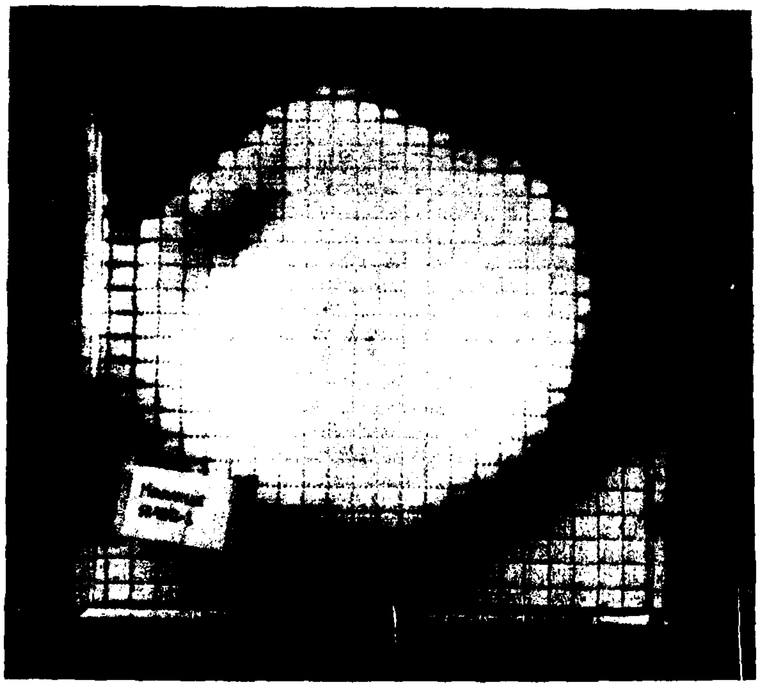

Figure B-24. Flexible Min-K^{R} HTS After Fire Penetration Test

Figure B-25. Flexible Min-K R HTS 758A Before Fire Penetration Test

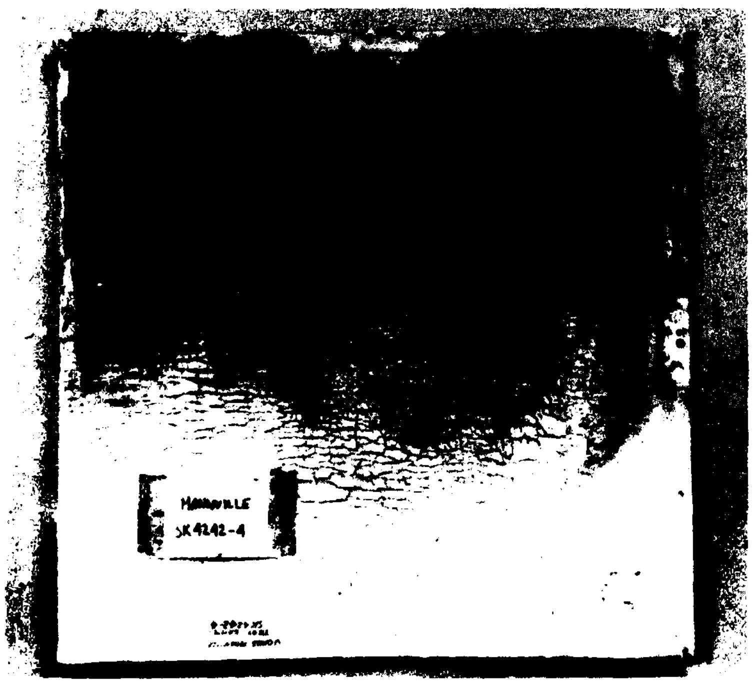

Figure B-26. Flexible Min-K R HTS 758A After Fire Penetration Test

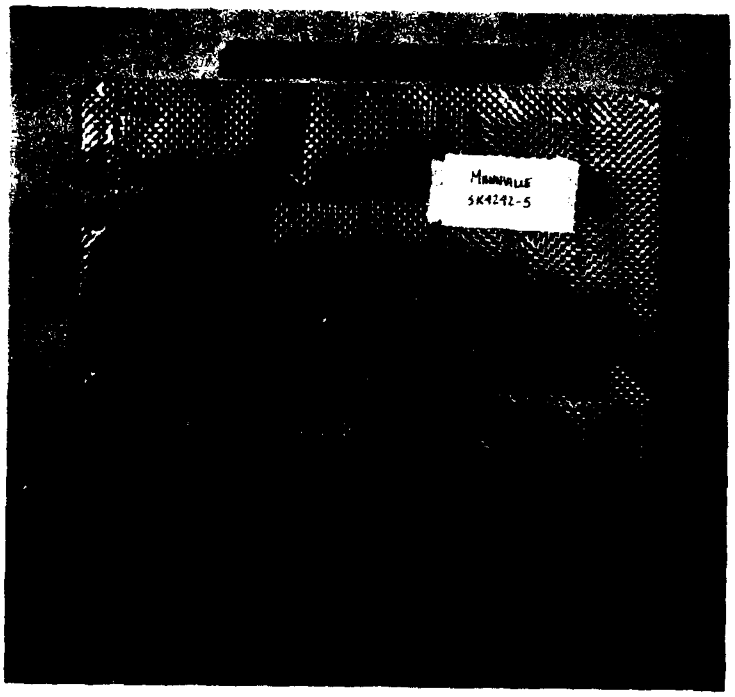

Figure B-27. Metal Clad SK4242Q Before Fire Penetration Test

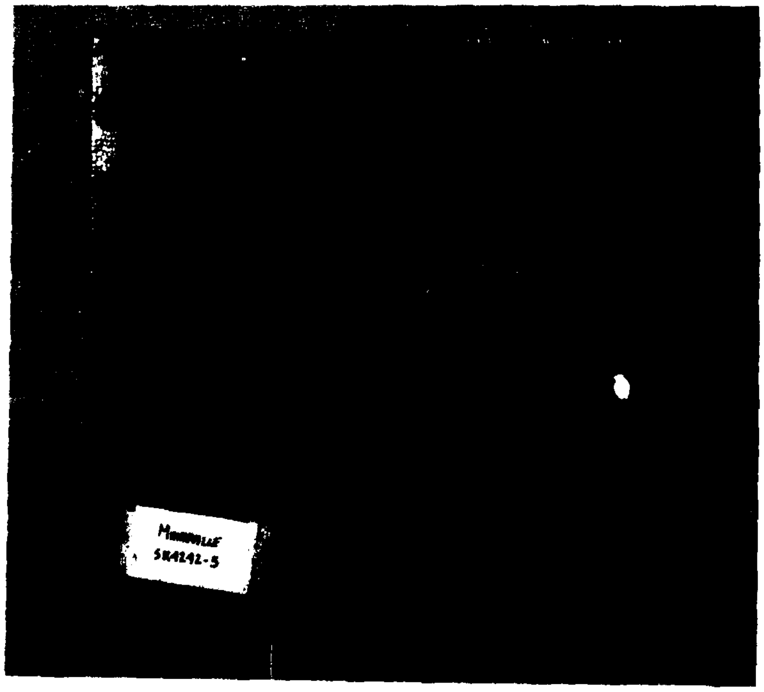

Figure B-28. Metal Clad SK4242Q After Fire Penetration Test

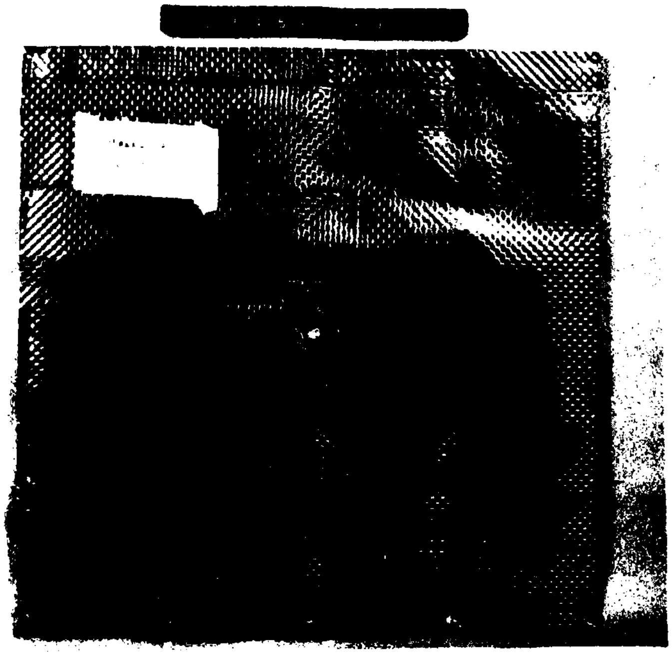

Figure B-29. Metal Clad SK4242C Before Fire Penetration Test

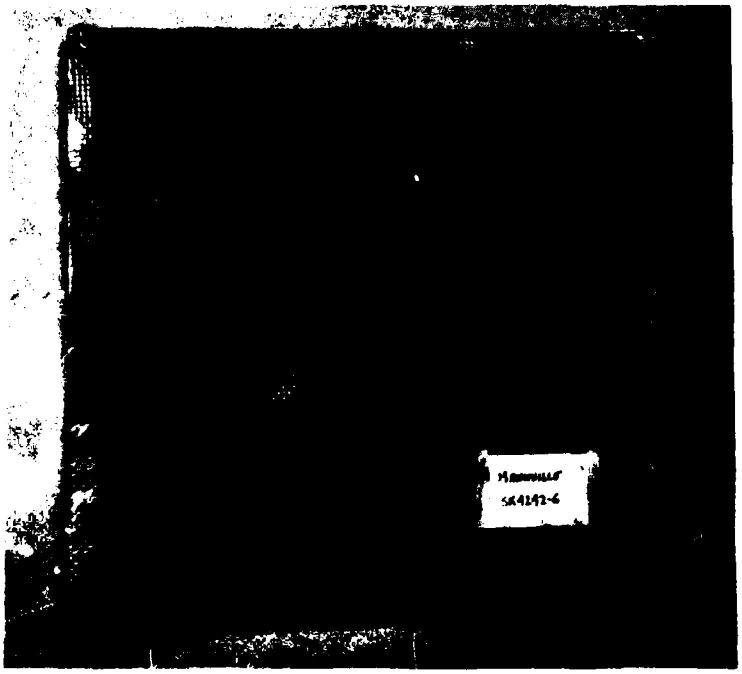

Figure B-30. Metal Clad SK4242C After Fire Penetration Test

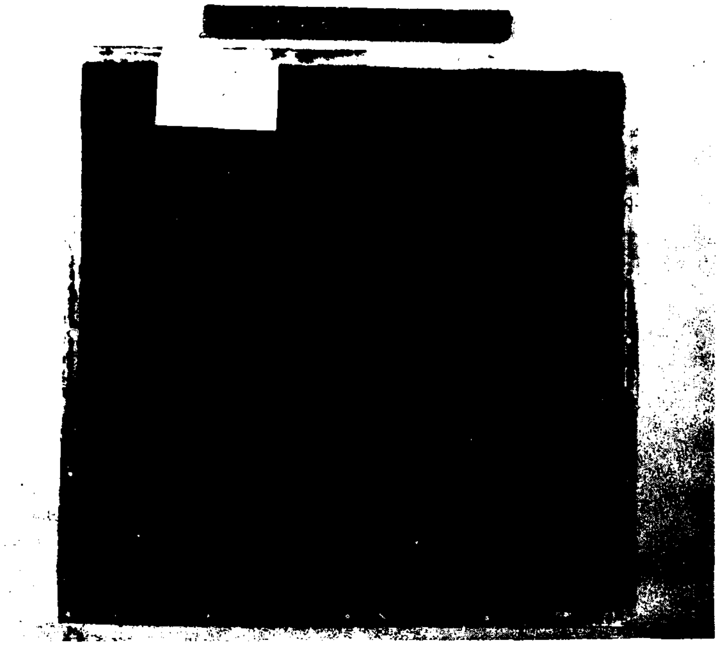

Figure B-31. Eccolite LN1478-39 #2 Before Fire Penetration Test

Figure B-32. Eccolite LN1478-39 #2 After Fire Penetration Test

AD-A155 765 INVESTIGATION OF EXPERIMENTAL LIGHTWEIGHT FIREWALL 2/3
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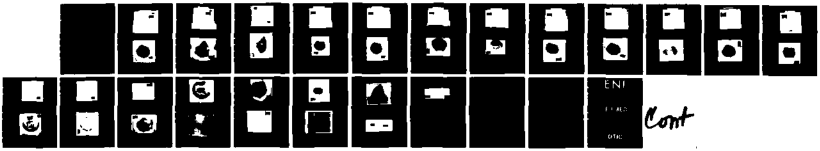
AERONAUTICAL LABS WRIGHT-PATTERSON AFB OH J J MOYER
UNCLASSIFIED APR 85 AFWAL-TR-84-2082 F/G 11/7 NL



Cont

1.0

1.1

1.25

1.4

1.6

2.8

3.2

3.6

4.0

2.5

2.2

2.0

1.8

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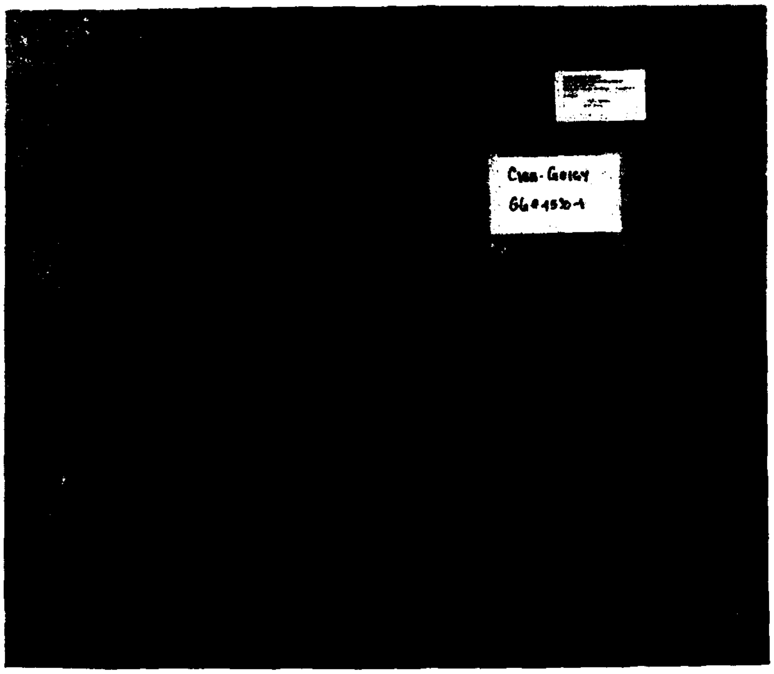

Figure B-33. CG #4530-1 Before Fire Penetration Test

Figure B-34. CG #4530-1 After Fire Penetration Test

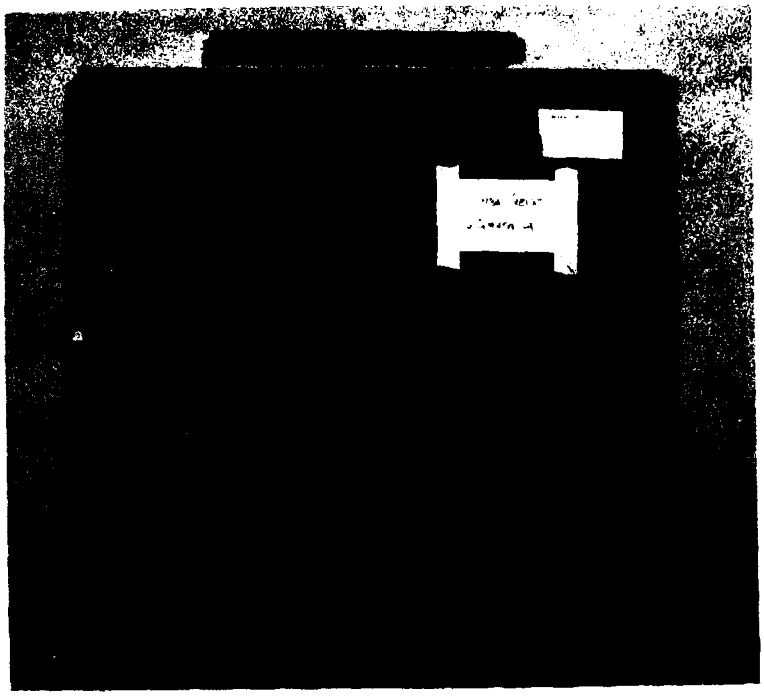

Figure B-35. CG #4530-4 Before Fire Penetration Test

Figure B-36. CG #4530-4 After Fire Penetration Test

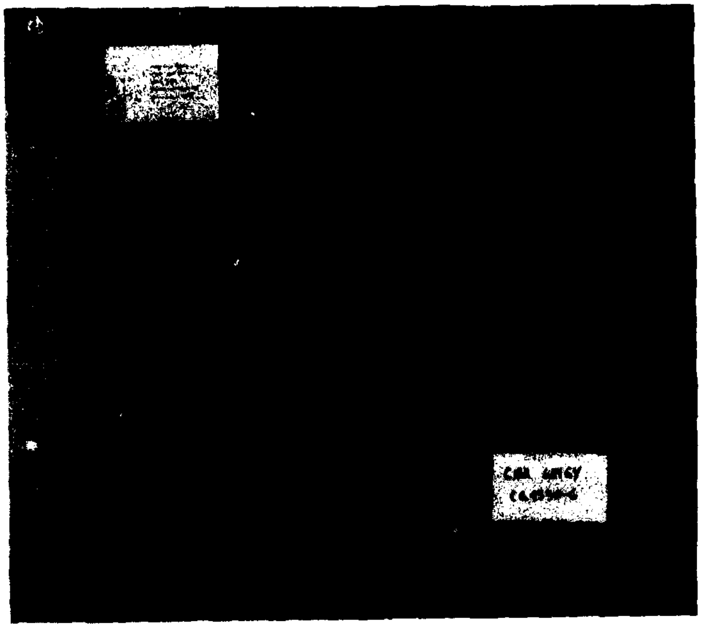

Figure B-37. Fibrelam R 3000 Before Fire Penetration Test

Figure B-38. Fibrelam R 3000 After Fire Penetration Test

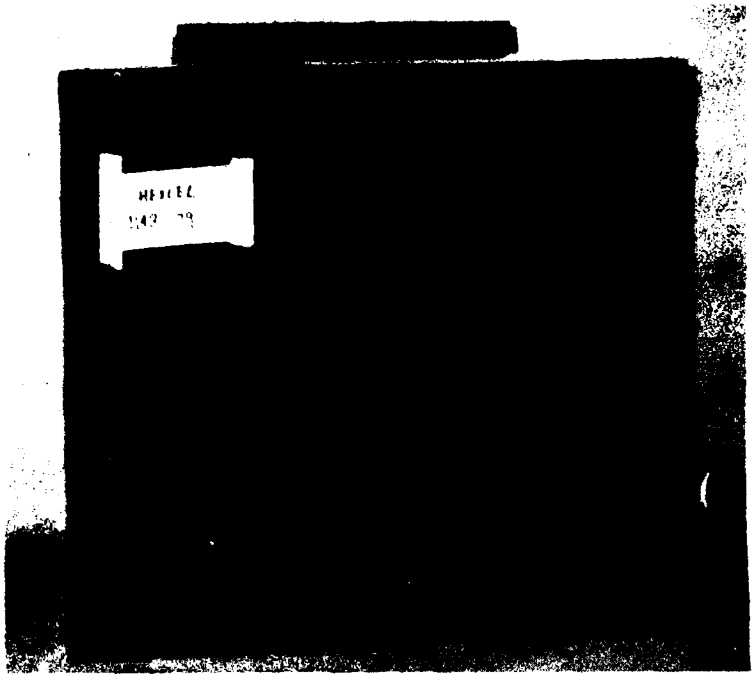

Figure B-39. F-263 Epoxy Resin Composite Firewall 114B-79 Before Fire Penetration Test

Figure B-40. F-263 Epoxy Resin Composite Firewall 114B-79 After Fire Penetration Test

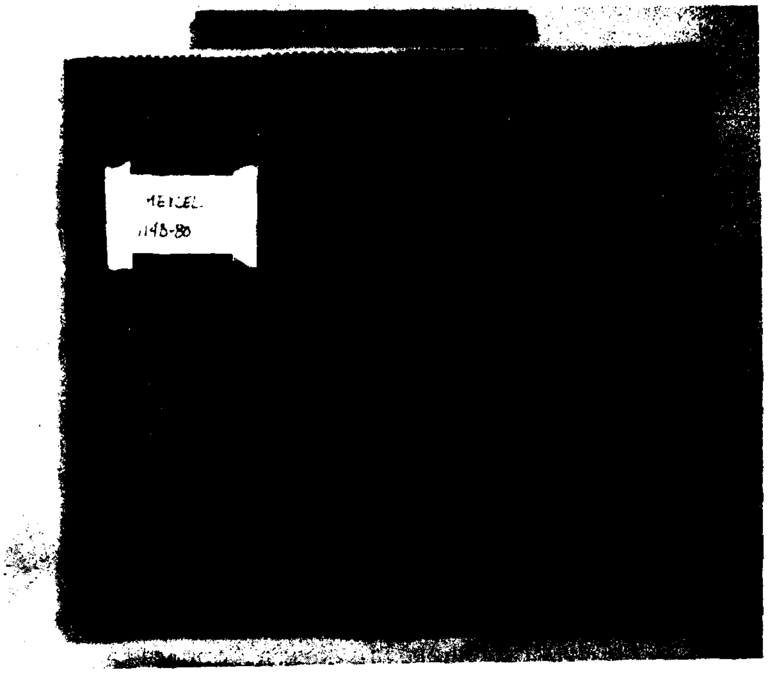

Figure B-41. F-263 Epoxy Resin Composite Firewall 114B-80 with Honeycomb Core Before Fire Penetration Test

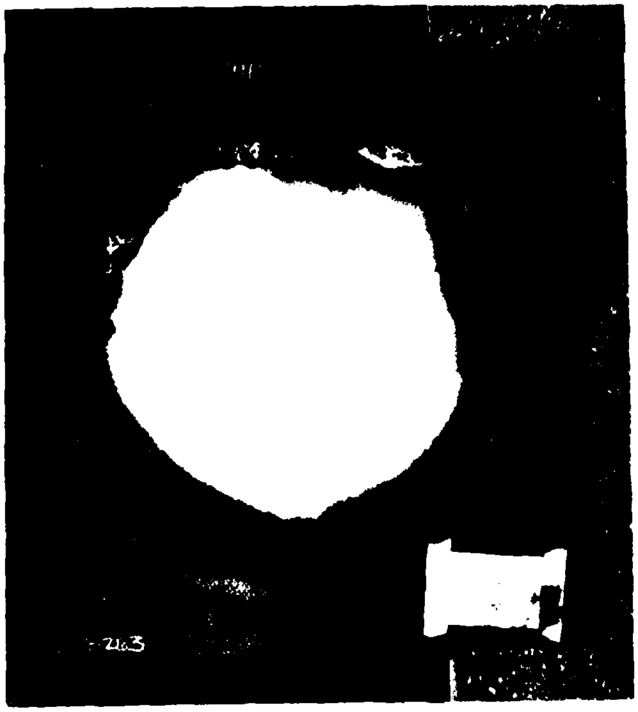

Figure B-42. F-263 Epoxy Resin Composite Firewall 114B-80 with Honeycomb Core After Fire Penetration Test

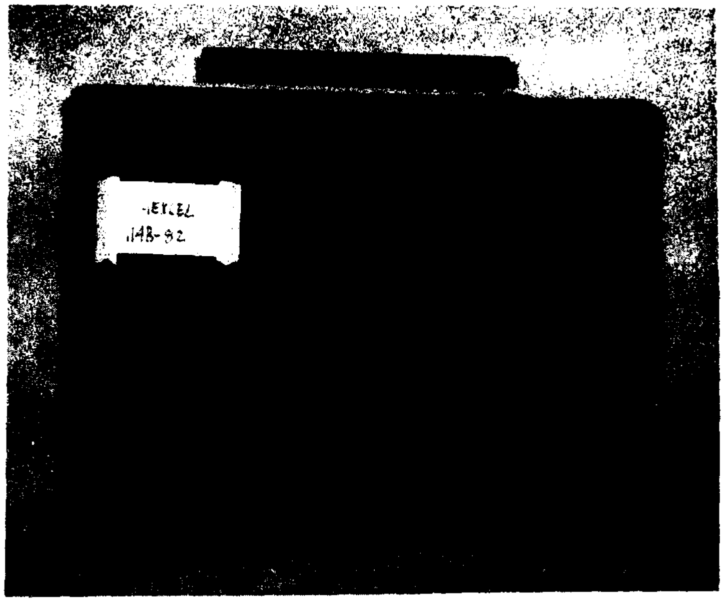

Figure B-43. F-120 Phenolic Resin Composite Firewall 114B-82 with Honeycomb Core Before Fire Penetration Test

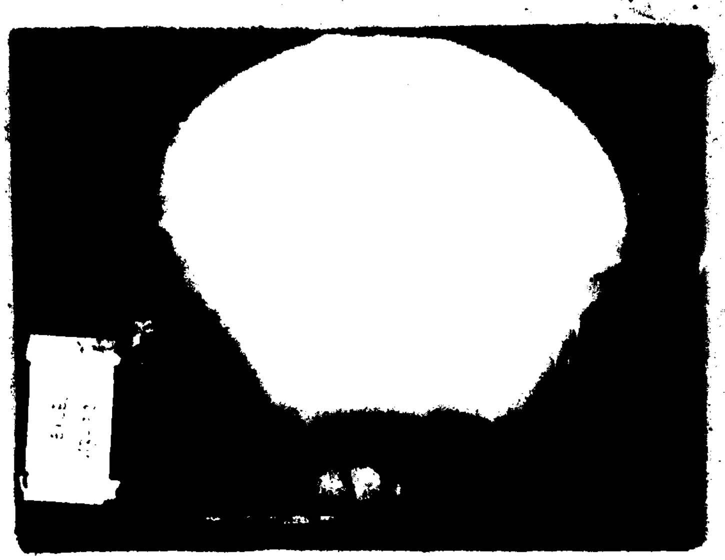

Figure B-44. F-120 Phenolic Resin Composite Firewall 114B-82 with Honeycomb Core After Fire Penetration Test

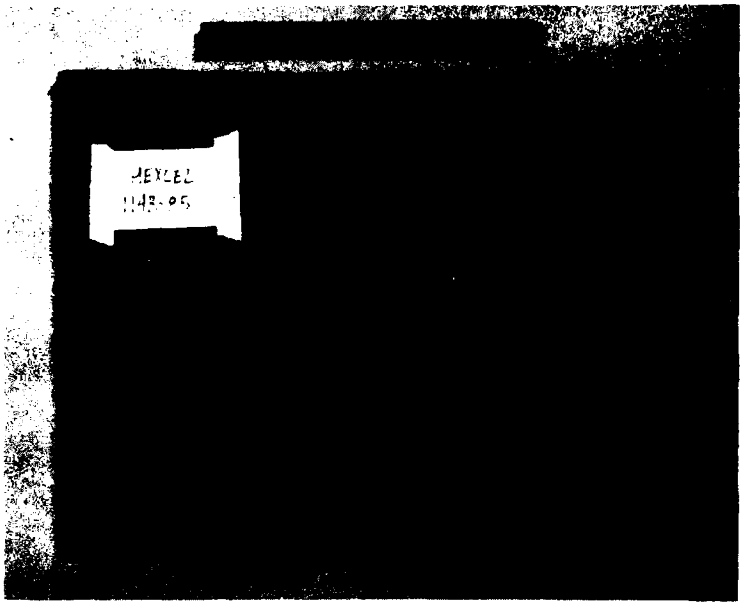

Figure B-45. F-825 Phenolic Resin Composite Firewall 114B-85 with Honeycomb Core Before Fire Penetration Test

Figure B-46. F-825 Phenolic Resin Composite Firewall 114B-85 with Honeycomb Core After Fire Penetration Test

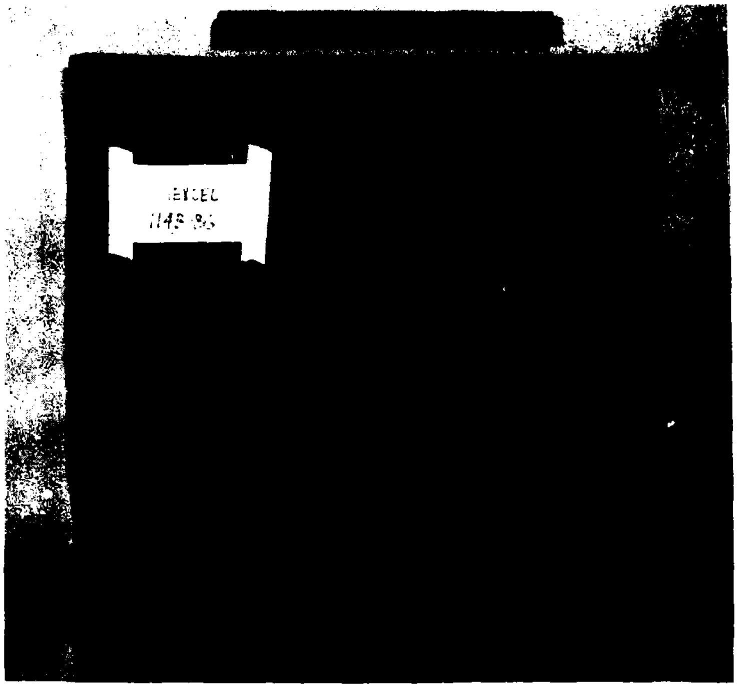

Figure B-47. F-174 Polyimide Resin Composite Firewall 114B-86 Before Fire Penetration Test

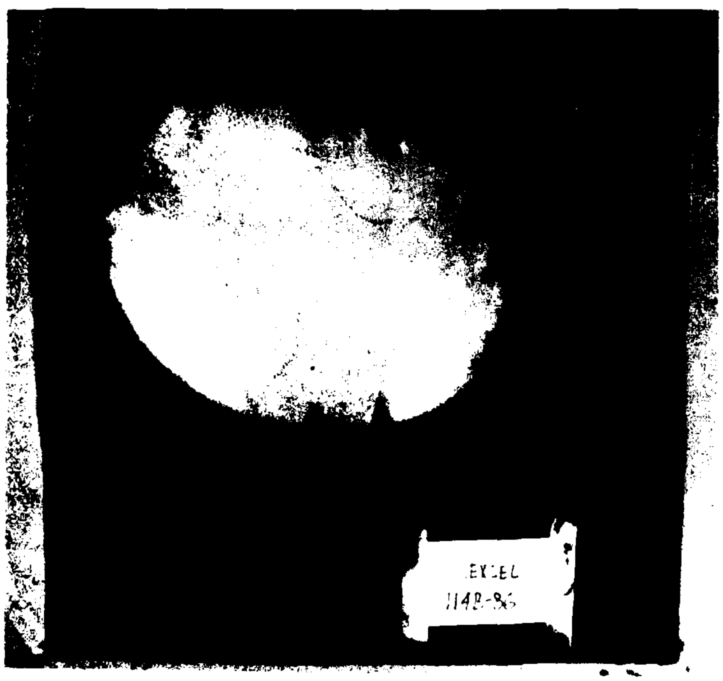

Figure B-48. F-174 Polyimide Resin Composite Firewall 114B-86 After Fire Penetration Test

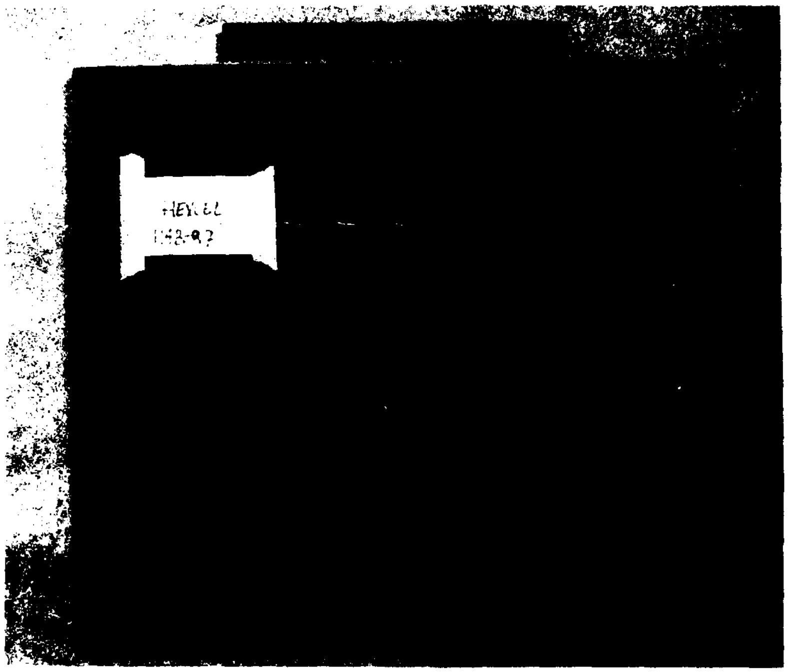

Figure B-49. F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core Before Fire Penetration Test

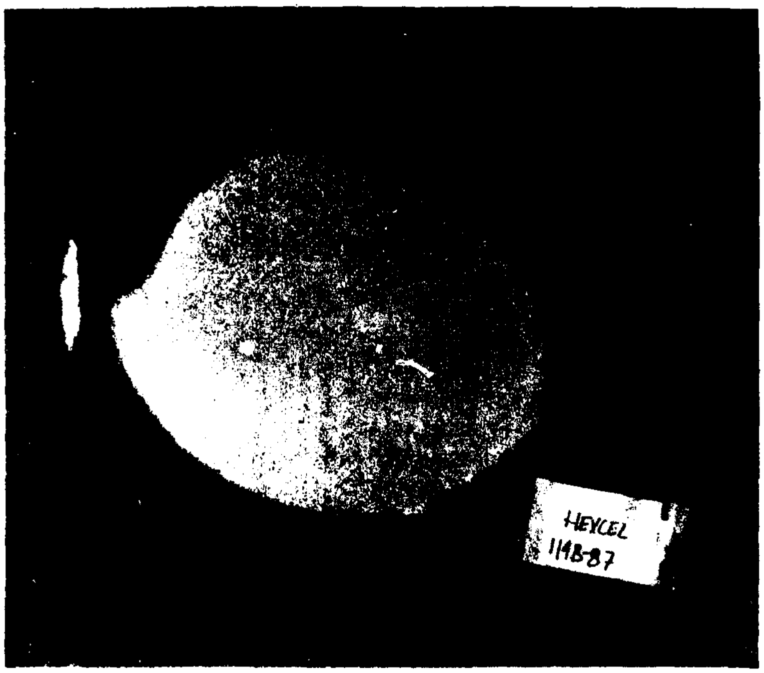

Figure B-50. F-174 Polyimide Resin Composite Firewall 114B-87 with Honeycomb Core After Fire Penetration Test

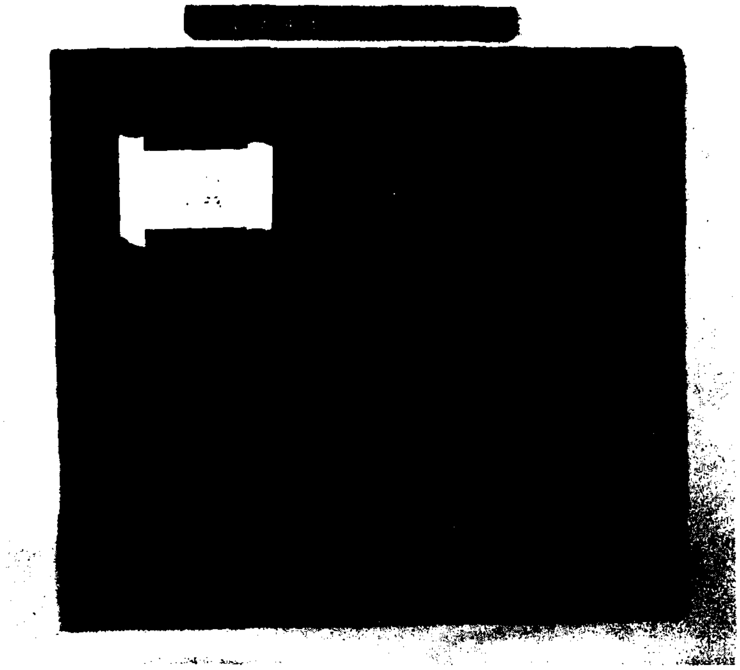

Figure B-51. F-178 BMI Resin Composite Firewall 114B-88 Before Fire Penetration Test

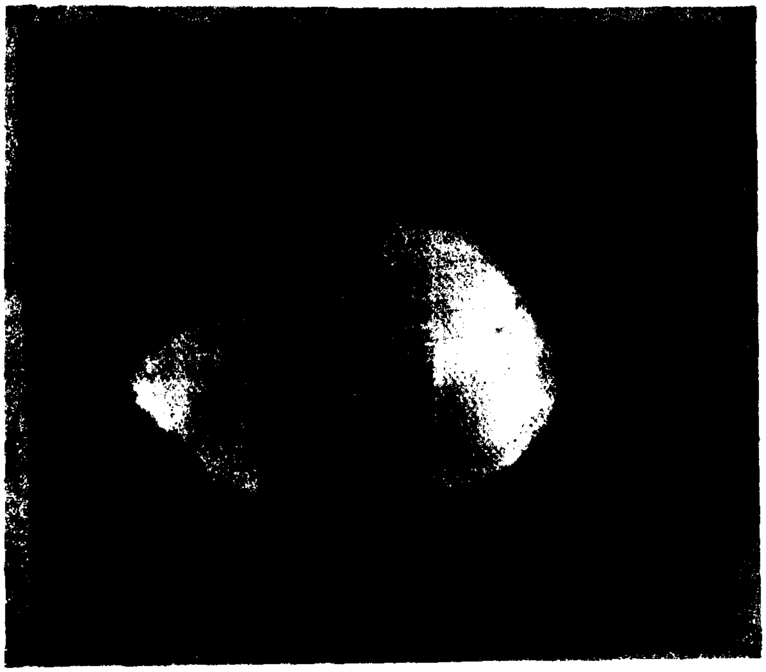

Figure B-52. F-178 BMI Resin Composite Firewall 114B-88 After Fire Penetration Test

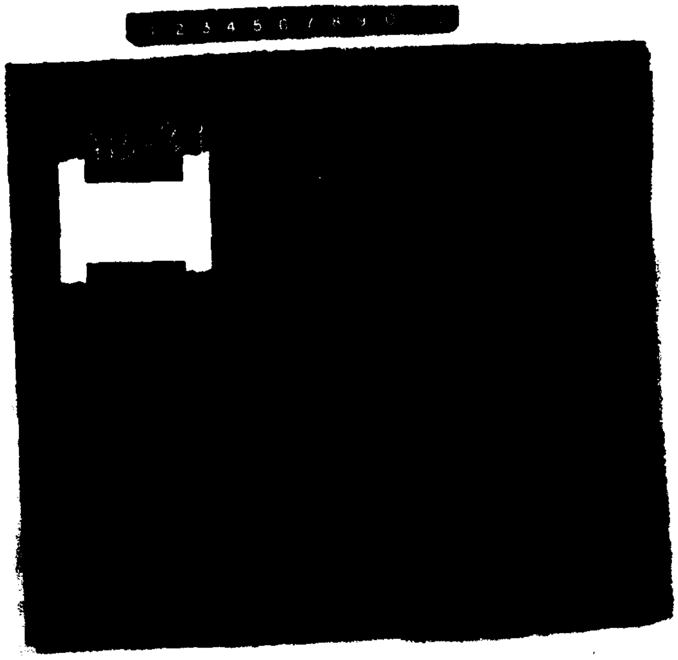

Figure B-53. F-178 BMI Resin Composite Firewall 114B-89 with Honeycomb Core Before Fire Penetration Test

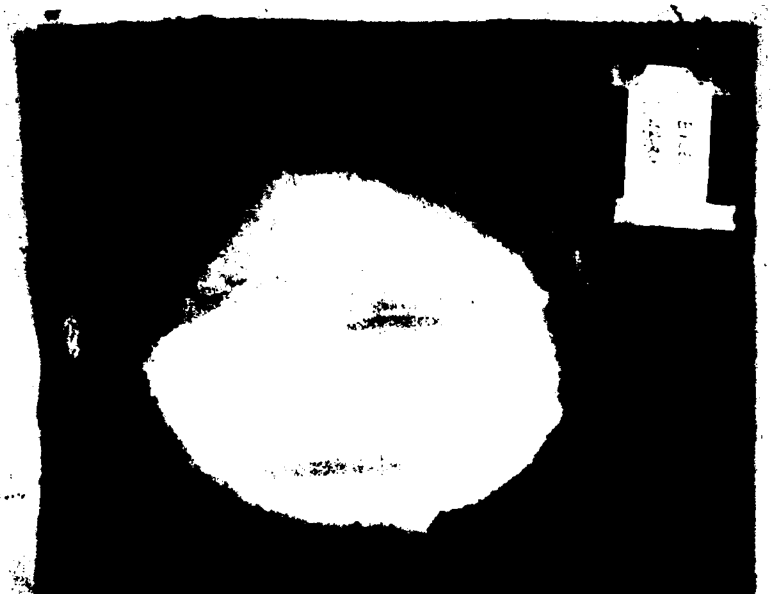

Figure B-54. F-178 BMI Resin Composite Firewall 114B-89 with Honeycomb Core After Fire Penetration Test

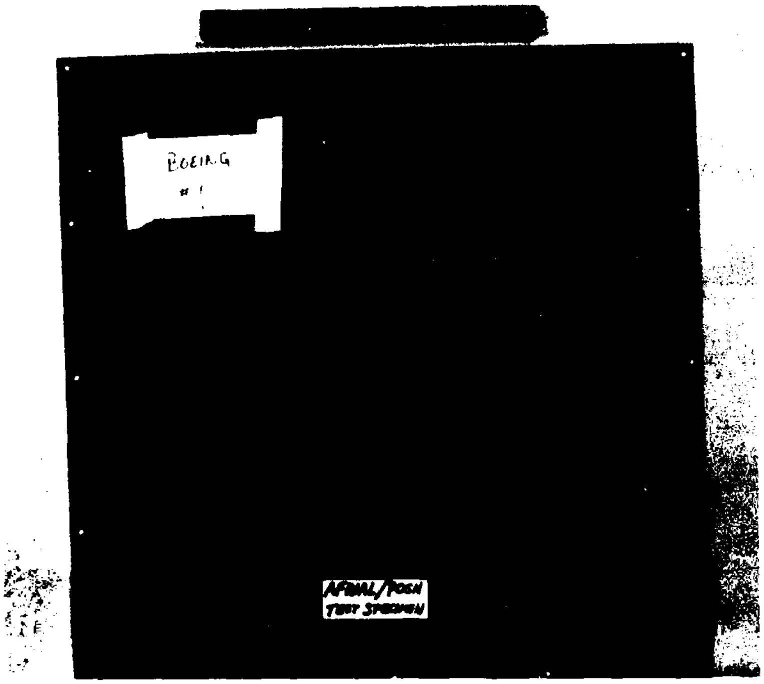

Figure B-55. Boeing Symmetrical Nextel ^{R}-Graphite Panel Before Fire Penetration Test

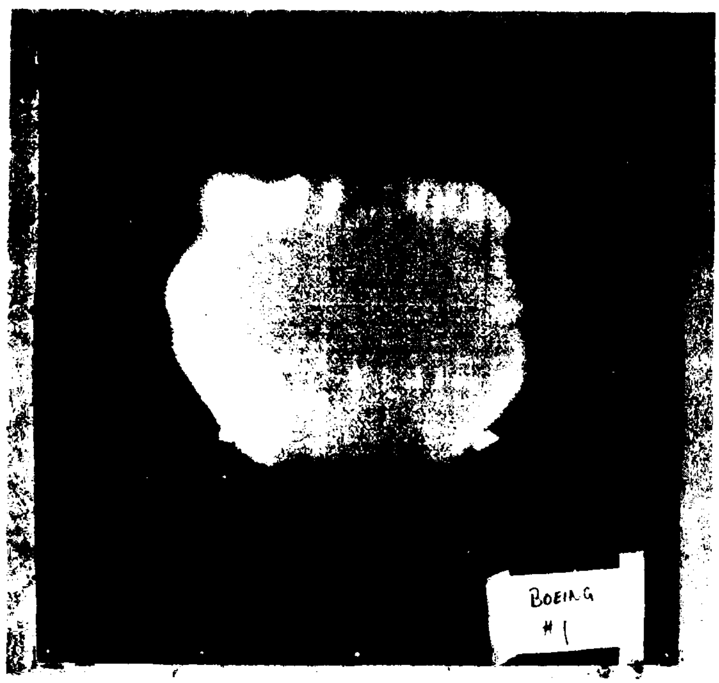

Figure B-56. Boeing Symmetrical Nextel ^{R}-Graphite Panel After Fire Penetration Test

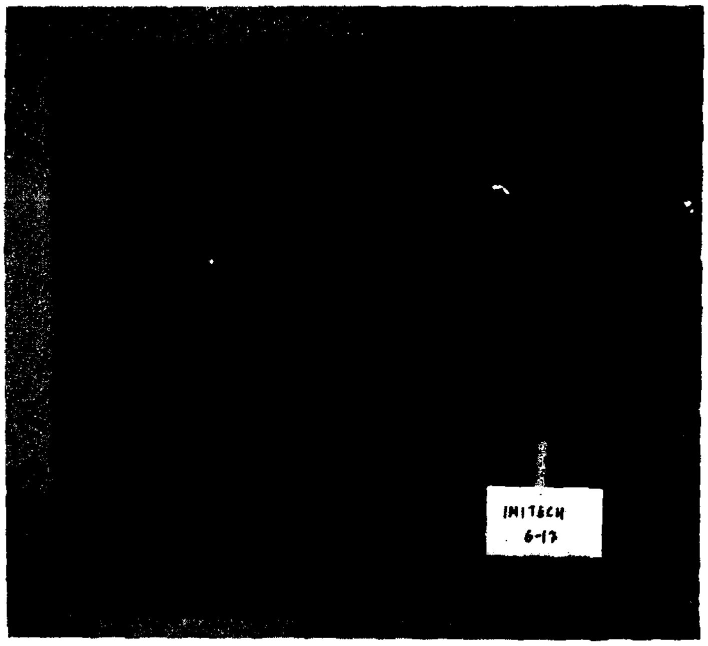

Figure B-57. Solimide [R] BD6F-13 Before Fire Penetration Test

Figure B-58. Solimide [R] BD6F-13 After Fire Penetration Test

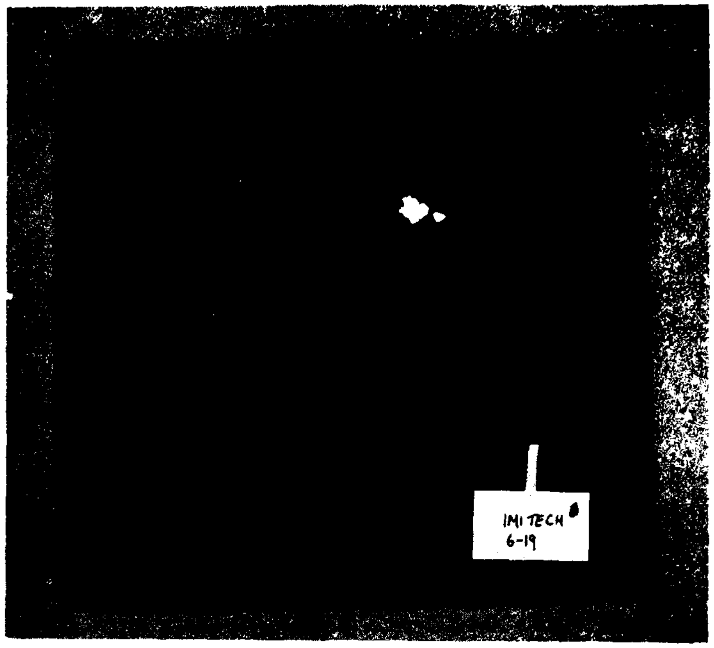

Figure B-59. Solimide ^{R} BD6M-11 Before Fire Penetration Test

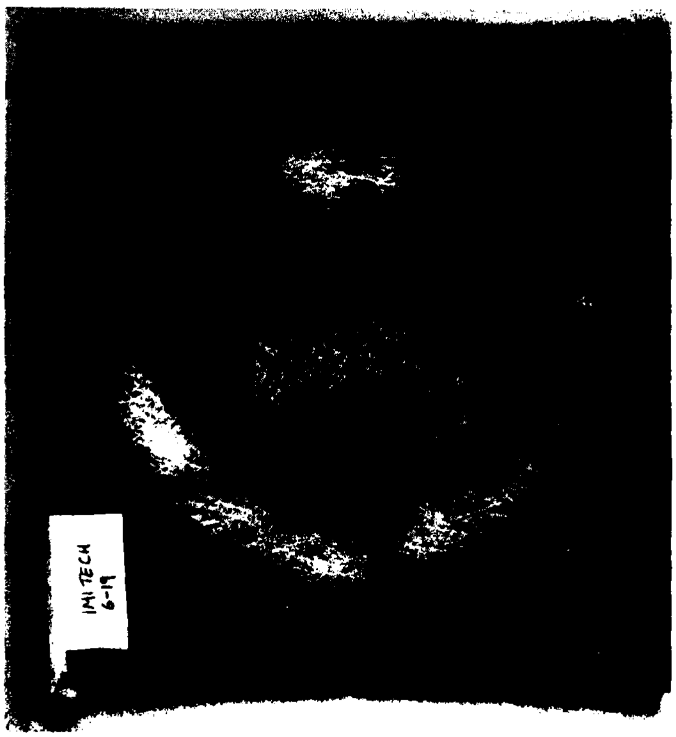

Figure B-60. Solimide ^{R} BD6M-11 After Fire Penetration Test

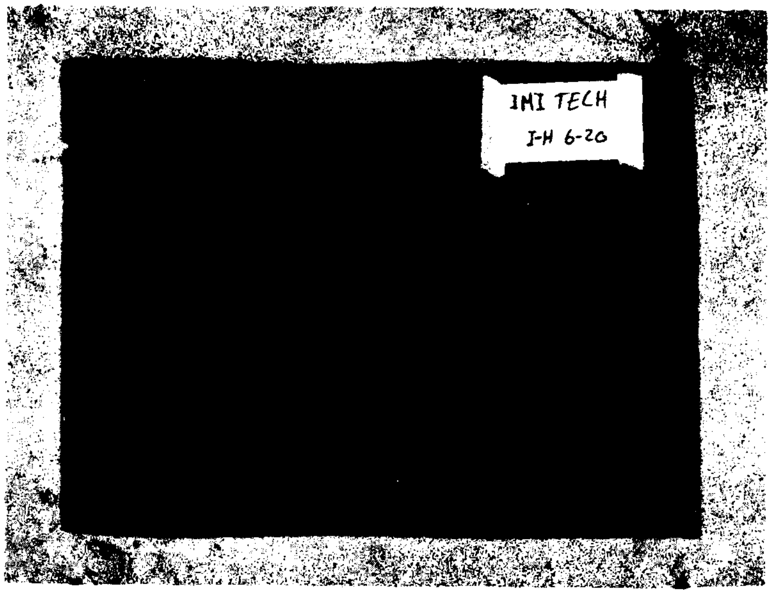

Figure B-61. Solimide ^{R} GL8S-180 Before Fire Penetration Test

Figure B-62. Solimide ^{R} GL8S-180 After Fire Penetration Test

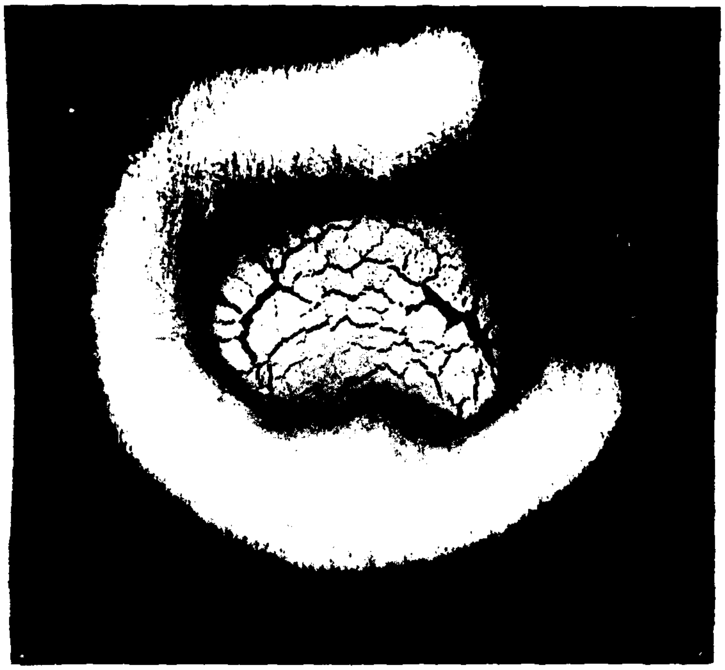

*Figure B-63. Solimide ^{R} BD5M-12 After Fire Penetration Test

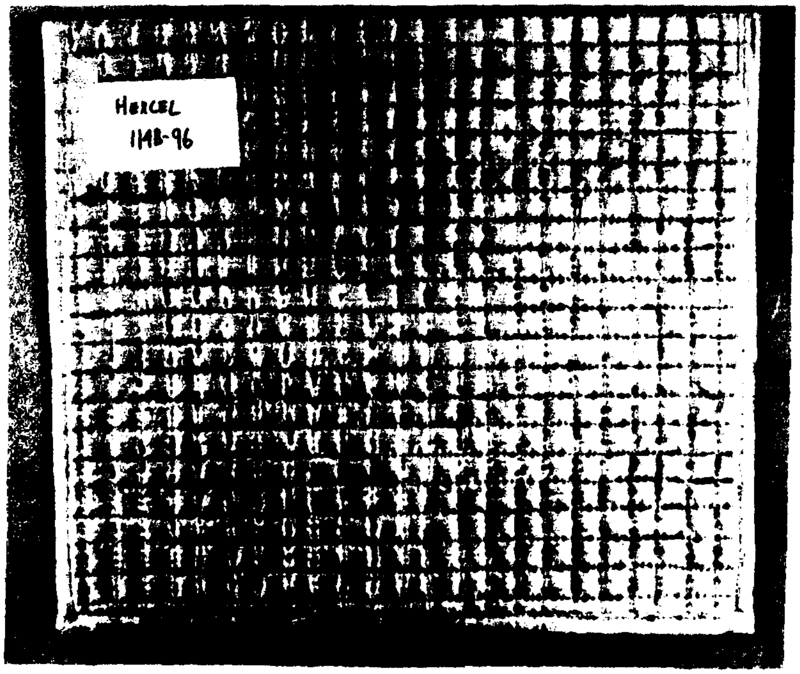

Figure B-64. F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket Before Fire Penetration Test

*NOTE: Picture of Sample Before Test not Available

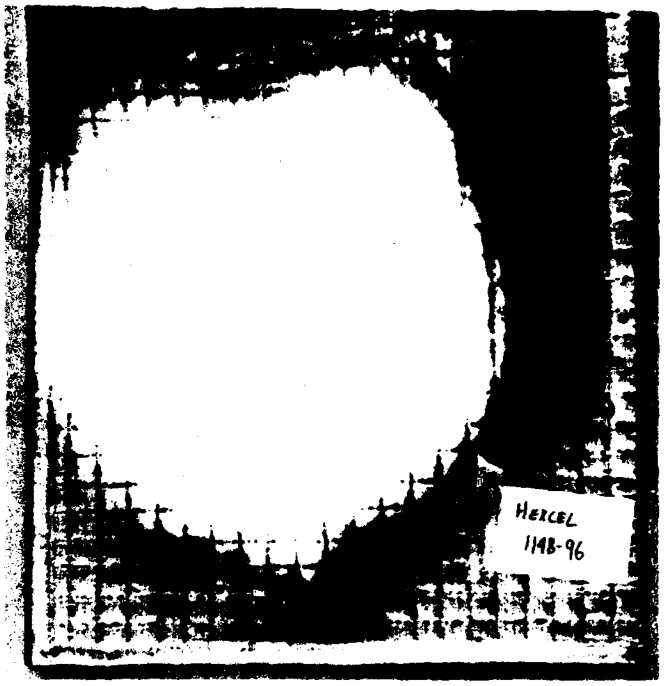

Figure B-65. F-174 Polyimide Resin Composite Firewall 114B-96 with Filled Honeycomb Core and S-Glass Blanket After Fire Penetration test

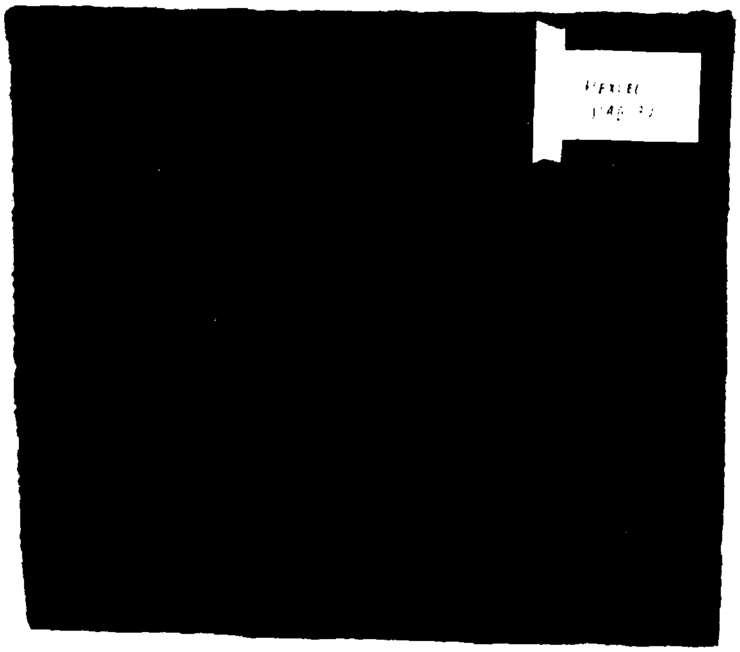

Figure B-66. F-174 Polyimide Resin Composite Firewall 114B-97 with Filled Honeycomb Core Before Fire Penetration Test

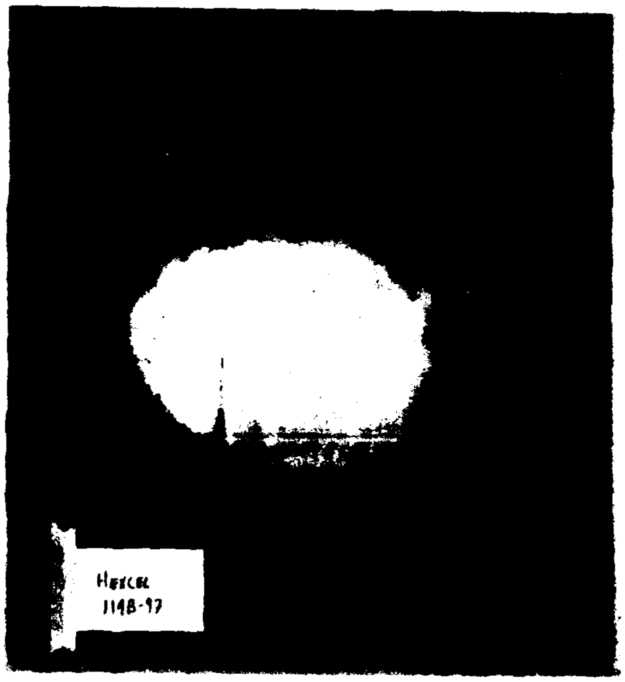

Figure B-67. F-174 Polymide Resin Composite Firewall 114B-97 with Filled Honeycomb Core After Fire Penetration Test

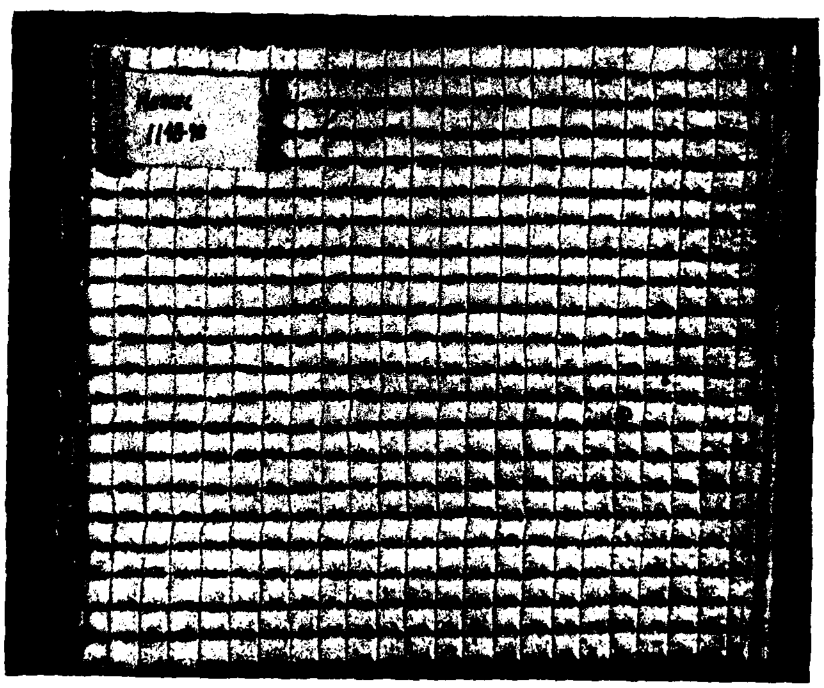

Figure B-68. F-174 Polyimide Resin Composite Firewall 114B-98 with Honeycomb Core and Ceramic Blanket Before Fire Penetration Test

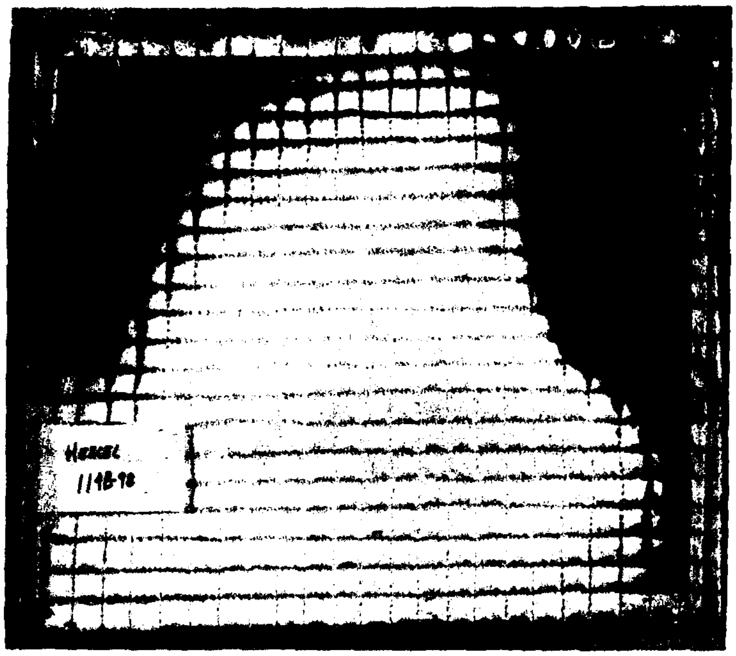

Figure B-69. F-174 Polyimide Resin Composite Firewall 114B-98 with Honeycomb Core and Ceramic Blanket After Fire Penetration Test

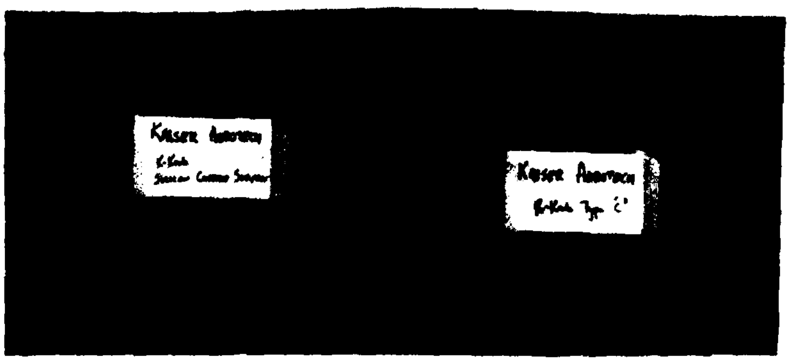

Figure B-70. K-Karb Type "C" and K-Karb with Silicon Carbide Converted Surface Before Fire Penetration Test

Figure B-71. K-Karb Type "C" and K-Karb with Silicon Carbide Converted Surface After Fire Penetration Test

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5. James E. Demaree, Re-evaluation of Burner Characteristics for Fire Resistance Tests, Federal Aviation Administration, Atlantic City NJ, FAA-RD-76-213, 1977.

6. E.P. Burke, Power Plant Engineering Report No. 3A - Standard Fire Test Apparatus and Procedures (for Flexible Hose Assemblies), Federal Aviation Administration, revised March 1978.

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4. Fell, Barry M. and Peter Ciriscioli, "The First All Composite Firewall as Developed and Designed for the Lear Fan 2100," 28th National SAMPE Symposium and Exhibition, 1983.

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Government Printing Office: 1985 — 559-065/20789

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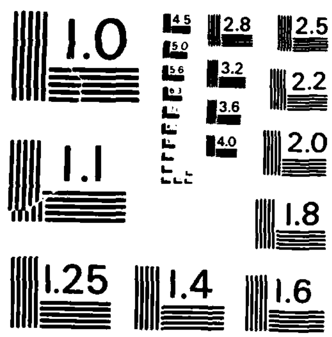
SUPPLEMENTARY

INFORMATION



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SUPPLEMENTARY

INFORMATION

Errata Sheet

AFWAL-TR-84-2082, "Investigation of Experimental Lightweight Firewall Materials for A/C Engine Bay Applications"

1. Page 6, line 5, "compete" should be "complete".

2. Page 27, #37, "114B-98" should be "114B-97".

3. Page 29, line 16, "13" should be "14".

4. Page 47, "N/A" means: NOT AVAILABLE, not: NOT APPLICABLE.

5. Page 53, add to first paragraph: "The Boeing sample was not included in the ranking because no data was available on its environmental limitations and maintenance requirements. However, this sample should be included in future testing based on its superior performance."

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